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A MANUAL  
OF  
ELECTRO-METALLURGY.

BY  
GEORGE SHAW.

SECOND EDITION, CONSIDERABLY ENLARGED.

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MANUAL

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## PREFACE TO THE FIRST EDITION.

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THE following pages contain the principal facts of the Art of Electro-Metallurgy.

The author has endeavoured to introduce everything interesting to the experimenter in this novel art; but has at the same time sought to make the work as brief as possible, by the omission of some of the minute details of manipulation. To the beginner this may appear discouraging, but in the end he will find it to his advantage; for although by giving minute directions in the manipulatory processes, a person wholly unacquainted with the principles on which those processes are founded, may *possibly* succeed in his experiments, yet the *probability* is that he would fail in the majority of cases, and would find himself compelled to master the principles of the science of Voltaic Electricity, before he could proceed to his experiments with certainty of success.

The author would not be understood to mean that the subject of manipulation has been neglected; on the contrary, he has endeavoured to introduce all that is essential; and he



believes that a careful perusal of the following pages, combined with that knowledge which experiment *alone* can give, will enable any one to practice the Art of Electro-Metallurgy, as far as it is at present developed.

As the facts stated in this work (with a few trifling exceptions,) have been experimentally verified by the author, he feels little doubt of their general accuracy.

*Temple Row West, Birmingham,  
May 16, 1842.*

THE present edition has been considerably enlarged by the introduction of recent discoveries in the art. The extent to which improvements have been introduced since the publication of the first edition, has rendered a more systematic arrangement necessary; the work has been divided into chapters, and many other alterations have been made, which, it is hoped, will make it more convenient and useful.

*Temple Row West, Birmingham,*  
*June 20, 1844.*



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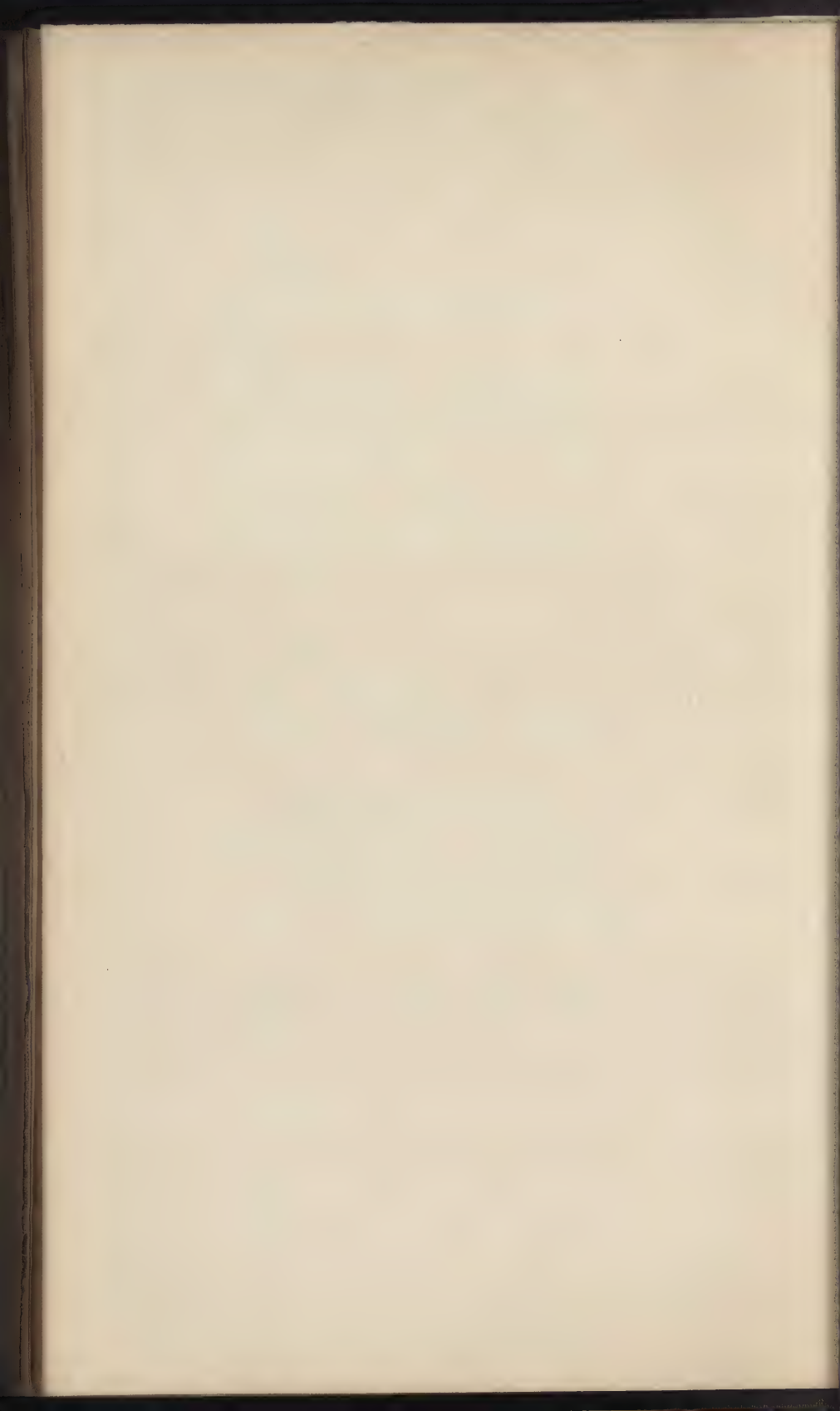
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CHAPTER I.

INTRODUCTION AND HISTORY.

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1. In reviewing the early history of the physical sciences, we cannot but be struck with the fact, that many discoveries, which now either minister to our wants, or add to our enjoyments, lay for a long time after their announcement wholly neglected, or at best, served but to swell the pages of the historian. It is not so, however, in modern times; no sooner is a discovery now made, than its application to some useful purpose is attempted; and at this moment there are, probably, hundreds anxiously watching the progress of discovery, eager for the announcement of some fact, which may be made available for purposes of use or ornament.

2. No department of science more strikingly exemplifies these remarks, than that branch of the science of electricity which the following pages are intended to illustrate, namely, the precipitation of metals by voltaic agency. During the short period that has elapsed since the constant battery of Professor Daniell was made public, a fact presented by the action of that instrument, has given rise to a new application of the voltaic battery, which has already effected the most important changes in the production of works of art. In treating of the voltaic battery, we shall fully describe the invention of Professor Daniell; it will suffice to notice in this place, that



the solution of sulphate of copper used in the excitation of that instrument, suffers rapid decomposition, and that the metallic copper which is precipitated, attaches itself closely to the copper cylinder in which the solution is contained, and it is found, on detaching the precipitated metal, that it had been deposited in such intimate contact with the copper cylinder, that the most minute marks are faithfully copied. The application of this fact constitutes the electrotype,—the earliest branch of the art of electro-metallurgy.

3. From this it would appear, that the history of the art is so simple as to require no comment, and so modern as to admit of no dispute; such, however, is not the case. It is a subject which has given rise to the most angry discussions, and concerning which even now opinion is strangely divided.

4. The earliest recorded process in electro-metallurgy is contained in the *Philosophical Magazine*.\* Brugnattelli relates, in a letter to Van Mons, that he had deposited a film of gold on ten silver medals, “by bringing them into communication by means of a steel wire with the negative pole of a voltaic pile, and keeping them, one after the other, immersed in ammoniuret of gold newly made and well saturated.” This announcement of a process identical with those now extensively used, attracted no attention at the time it was made, and its existence has only been recently pointed out by Mr. Brayley.

5. The earliest experimenters with the voltaic pile, observed the precipitation of metals in the voltaic circuit. The precipitation of copper was distinctly noticed by Mr. Nicholson in a paper entitled “Account of the New Electrical Apparatus of Sig. Alex. Volta, and Experiments performed with the same. W. N.”† The following passage is extracted from this paper. “When copper wires were used for the broken circuit, with muriatic acid diluted with 100 parts of water

\* Phil. Mag. 1805.

† Nicholson's Journal, July, 1800, p. 179.

in the tube, no gas nor the least circulation of the fluid was perceived, when the distance of the wires was two inches. A short tube with two copper wires very near each other, in common water, was made part of the circuit, and showed, by the usual phenomena, that the stream of electricity was rapidly passing. The wires in the muriatic acid were then slid within a third of an inch of each other. For the sake of brevity, I avoid enumerating the effects which took place during several hours, and simply state, that the minus wire gave out some hydrogen during an hour, while the plus was corroded, and exhibited no oxide, but a deposition of copper was formed round the minus or lower wire, which began at its lower end; that no gas whatever appeared in this tube during two hours, though the deposition was going on, and the small tube showed the continuance of the electric stream; and that the deposition at the end of four hours formed a ramified metallic vegetation, nine or ten times the bulk of the wire it surrounded. In this experiment it appeared, that the influence of electricity increasing the oxidability of the upper wire, and affording nascent hydrogen from the lower, caused the latter to act as the precipitant of a solution of one and the same metal."

6. Voltaic precipitation of the metals was observed about the same time by Mr. Cruikshank, as the following extracts from his paper, "Some Experiments and Observations on Galvanic Electricity," will shew.\* "The tube was filled with a solution of the acetite of lead, to which an excess of acid was added, to counteract the effects of the alkali. When the communication was made in the usual way, no gas could be perceived, but after a minute or two, some fine metallic needles were perceived at the extremity of the wire connected with the silver. These soon increased, and assumed the form of a feather, or rather, that of the crystals of the muriate of

\* Nicholson's Journal, July, 1800, p. 187.

ammonia. The lead thus precipitated was perfectly in its metallic state and very brilliant; a little gas escaped from the wire connected with the zinc, and it was considerably corroded as usual. A solution of the sulphate of copper was next employed, and with the same result, the copper being precipitated in its metallic form by the wire connected with the silver. In this instance the metal did not crystallize, but formed a kind of button at the end of the wire, which adhered so completely to the silver, that it was found impossible to separate it. The most beautiful precipitate, however, was that of silver from its solution in the nitrous acid. In this case, the metal shot into needle-like crystals articulated or joined to each other as in the *arbor Diana*.\* The same philosopher also remarks as follows, in his "Additional Remarks on Galvanism:"\*—"Having found that the solutions of metals in acids were decomposed by this influence (voltaic electricity), I next wished to ascertain if their solutions in alkalies, more particularly in ammonia, could be decomposed in the same way. For this purpose, I added to a dilute solution of the nitrate of silver some pure ammonia, until the mixture smelled strongly of the latter substance. This mixture was introduced into a glass tube secured by corks in the usual way, and silver wires applied. When the tube was placed in the circle of communication, a very rapid production of gas took place from the wire connected with the silver extremity of the machine, although but little or none escaped from the zinc wire during the whole process."

7. "After some time, a quantity of greyish flakes, evidently of metallic silver, were separated by the wire which gave out the gas, and a dark grey powder was deposited on the zinc wire; at this period of the process much less gas was disengaged, although a considerable quantity still appeared at the silver wire. After some hours, the apparatus was removed;

\* Nicholson's Journal, July, 1800, p. 254.



at this time a very considerable quantity of metallic silver was deposited, and the zinc wire was encrusted with a blueish black substance. On endeavouring to remove this crust with the finger, part of it exploded, although still moist." . . . . "This experiment was repeated, and instead of a solution of silver, nothing but pure ammonia was introduced into the tube, which answered exceedingly well ; for the silver of the zinc wire, after being corroded &c., was immediately taken up by the vol. alkali and afterwards deposited in its metallic form by the silver wire." "I next filled the tube with an ammoniacal solution of copper, and employed copper wires. In a very short time after this had been exposed to the action of the machine, the upper part of the fluid in contact with the silver wire became considerably paler, and copper was precipitated. In about an hour, the whole of the fluid in this part of the tube became as colourless as distilled water, so completely had the metal been precipitated. The precipitated metal was also the purest I had ever seen. From these experiments it would appear, that the galvanic influence might be employed with success in the analysis of minerals, more particularly in separating lead, copper and silver, from their different solutions. A very small quantity of a metal may likewise be detected in this way, as I have found from direct trial."

8. From the time Brugnatelli's experiment was announced, till the year 1830, no experiments on the application of electricity to the deposition of metals for the purposes of art were published. On the 25th of November in that year, a paper by Mr. Edmund Davy was read before the Royal Society, in which he distinctly states that he had gilded, silvered, coppered, and tinned various metals by the voltaic battery ; and although he does not give the disposition of the apparatus for reducing these metals, he describes accurately the means to be taken for procuring deposits of mercury, copper, lead, arsenic, and those metals the salts of which constitute the

more common poisons, and he states, that in a future communication he shall enter into the application of these facts to the purposes of gilding, plating, &c. ; but so far as the author is aware, the concluding part of his paper never appeared. There is, however, sufficient evidence of Mr. Davy's familiarity with the voltaic precipitation of the metals, in the paper from which the subjoined extracts are made, as well as such information as would have enabled any one to carry out the practical application of voltaic precipitation to useful purposes, had the value of such precipitations been as evident then as it is now. Mr. Davy's paper will be found in the *Philosophical Transactions of the Royal Society* for the year 1831, p. 147. The following are extracts.

9. "*On a Simple Electro-chemical Method of ascertaining the Presence of different Metals, applied to detect minute quantities of Metallic Poisons.* By EDMUND DAVY, F.R.S., &c." (Read Nov. 25, 1830.)—"It is now nearly a quarter of a century since the late Sir Humphry Davy, by a train of masterly researches, developed the general principles of electro-chemical action, which subsequently led him to many fine discoveries and important practical applications. Some years since, I repeated most of the interesting experiments noticed in his excellent Bakerian lecture, 'On the Chemical Agencies of Electricity.'"\* On the decomposition of metallic salts by the voltaic battery, Sir Humphry is very brief. He clearly ascertained, however, that "when metallic solutions were placed in the circuit, metallic crystals or depositions were formed on the negative surface," and that "the metals passed towards the negative surface, like the alkalies, and collected round it." "In the course of my experiments on this subject, phenomena occurred which led me to think that some novel results might be obtained by instituting a series of experiments on metallic salts, using, as a voltaic arrangement, the feeble

\* Phil. Trans. of the Royal Society, 1807.

power produced by the contact of small slips of different metals with solutions of the common metallic salts. Operating in this manner, I could readily detect very minute quantities of different metals, coat platina with gold, silver, copper, &c., or cover gold with a surface of these metals, and tin, copper, brass, iron, &c." . . . . "Circumstances which it is unnecessary to mention have hitherto prevented me giving greater publicity to these facts. . . . . The fear of trespassing too much on the time of the Society, induces me to limit the present paper to one part only of the subject. At no distant period I promise myself the pleasure of communicating the remaining part, which will embrace the different electrochemical experiments I have made on the other metals and their compounds, together with the application of the facts to the processes of gilding, silvering, tinning, &c."

10. These experiments of Brugnatelli and Davy having been completely lost sight of, do not affect the merit of succeeding experimenters; and the art cannot be said to have originated until after the origin of the constant battery.

11. It has already been remarked (2), that in Daniell's battery, metallic copper is precipitated on the copper cylinder containing the solution of the sulphate of that metal. This precipitated copper is not very intimately attached, for, by the application of a very moderate force, it may be torn off. This fact was known to Mr. Daniell, who shewed that the detached metal had been deposited in such close contact with the matrix, that it exhibited impressions of marks on the latter with extreme fidelity; he did not think, however, of applying this fact to any useful purpose. In the course of experiments made with this battery, other philosophers observed the same fact.

12. Mr. Warren de la Rue makes the following remarks in a paper "On the Effects of a Battery charged with Sulphate of Copper," published in the *London and Edinburgh Philosophical Magazine* for 1836. "The zinc plate is always par-

tially covered with a coating of copper, which, however, is not detrimental to the power of the battery ; the copper plate is also covered with a coating of metallic copper, which is continually being deposited ; and so perfect is the sheet of copper thus formed, that on being stripped off, it has the polish, and even a counterpart of every scratch, of the plate on which it is deposited."

13. In May, 1839, it was announced that Professor Jacobi, of St. Petersburg, could employ the voltaic battery in the reduction of copper for various purposes ; and to his art was given the name of Volta-Plastics.

14. The first account of the result of Jacobi's experiments which appeared in England was contained in a paragraph in the *Athenæum* for May, 1839, and was as follows :—" *Galvanic Engraving in Relief*.—While M. Daguerre and Mr. Fox Talbot have been dipping their pencils in the solar spectrum, and astonishing us with their inventions, it appears that Professor Jacobi, at St. Petersburg, has also made a discovery which promises to be of little less importance to the arts. He has found a method, if we understand our informant rightly, of converting any line, however fine, engraved on copper, into a relief, by a galvanic process. The Emperor of Russia has placed at the Professor's disposal funds to enable him to perfect his discovery." Immediately after this announcement, the following letter appeared in the *Mechanics' Magazine*.\*

15. "*Engraving by Galvanism*.—Sir,—Observing in the last page of a recent number of your Magazine a notice extracted from the *Athenæum*, relative to a discovery of Professor Jacobi, its perusal occasioned the recollection of some experiments performed about the commencement of last summer, with the view of obtaining impressions from engraved copper plates by the aid of galvanism, which led me to infer

\* June 8, 1839.



some analogy in principle with those of the Russian Professor, and may, probably, give me the right to claim priority in its discovery and application. These experiments were abandoned from the want of that most important element in pursuits of this nature, time; the writer's share of the said element being occupied in a manner more imperative than pleasing. I regret, however, not having made it the subject of an earlier communication, as this would have placed my pretensions beyond doubt; but inasmuch as the notice alluded to is given from memory, and is undescriptive, while I may be enabled to exhibit the *modus operandi*, my assertion may be at least partially substantiated.

16. "It is well known to experimentalists on the chemical action of voltaic electricity, that solutions of several metallic salts are decomposed by its agency, and the metal procured in a free state. Such results are very conspicuous with copper salts, which metal may be obtained from its sulphate, (blue vitriol) by simply immersing the poles of a galvanic battery in its solution, the positive one becoming gradually coated with copper. The phenomenon of metallic reduction is an essential feature in the action of sustaining batteries; the effects, in this case, taking place on more extensive surfaces. But the form of voltaic apparatus which exhibits this result in the most interesting manner, and relates more immediately to the subject of the present communication, may be thus described:—It consists of a glass tube, closed at one extremity with a plug of plaster of Paris, and nearly filled with a solution of sulphate of copper; this tube and its contents are immersed in a solution of common salt. A plate of copper is placed in the first solution, and is connected, by means of a wire and solder, with a zinc plate, which dips into the latter. A slow electric action is thus established through the pores of the plaster, which it is not necessary to mention here; the result of which is the precipitation of minutely-crystallized copper on the plate of that metal, in a state of greater or less

malleability, according to the slowness or rapidity with which it is deposited. In some experiments of this nature, on removing the copper thus formed, I remarked that the surface in contact with the plate equalled the latter in smoothness and polish, and mentioned this fact to some individuals of my acquaintance. It occurred to me, therefore, that if the surface of the plate was engraved, an impression might be obtained. This was found to be the case; for on detaching the precipitated metal, the most delicate and superficial markings, from the fine particles of powder used in polishing to the deeper touches of a needle or graver, exhibited their correspondent impressions in relief with great fidelity. It is therefore evident that this principle will admit of improvement, and that casts and moulds may be obtained from any form of copper.

17. "This rendered it probable that impressions may be obtained from those other metals having an electro-negative relation to the zinc plate of the battery. With this view, a common printing type was substituted for the copper plate and treated in the same manner; this also was successful; the reduced copper coated that portion of the type immersed in the solution. This, when removed, was found to be a perfect matrix, and might be employed for the purpose of casting, where time is not an object.

18. "It appears, therefore, that this discovery may be turned to some practical account. It may be taken advantage of in procuring casts from various metals, as above alluded to; for instance, a copper disc may be formed from a cast of a coin or medal, in silver, type metal, or lead, &c., which may be employed for striking impressions in soft metals. Casts may probably be obtained from a plaster surface surrounding a plate of copper; tubs [tubes?] or any small vessel may also be made by precipitating the metal around a wire, or any kind of surface to form the interior, which may be removed mechanically, by the aid of an acid solvent, or by heat."

"May 22, 1839."

"C. J. JORDAN."

19. On the 8th of May, 1839, Mr. Thos. Spencer, of Liverpool, announced to the Polytechnic Society of that town, that he had a communication to make to the society relative to the application of electricity to the arts, and that he then gave notice of that communication, in consequence of a paragraph having appeared in the public prints, announcing that Professor Jacobi had applied the voltaic battery to the production of works of art.

20. Mr. Spencer's first communication to the public was on the 12th of September, 1839. His paper was to have been read at the meeting of the British Association in Birmingham, but, for some unexplained reason, it was suppressed. It was subsequently read before the members of the Liverpool Polytechnic Society on the day above mentioned. In this paper (which was afterwards published) Mr. Spencer details the circumstances which suggested to him this application of voltaic electricity. He observed, during one of his experiments, that a copper plate which he had been using as a negative element in a voltaic arrangement, in which a solution of sulphate of copper was employed, had become covered with the precipitated metal in every part, excepting in two or three places where by accident some drops of varnish had fallen; it immediately occurred to him, that if a plate of varnished copper, having a design made upon it by a pointed instrument so as to remove the varnish, were made the negative plate of a voltaic arrangement, the copper would be precipitated on the parts where the metal was exposed, so that on removing the varnish the design would be left in relief; experiment confirmed the correctness of his conjecture.

12. In the same paper, Mr. Spencer relates another experiment which suggested to him that application of voltaic electricity, which is at present known as the Electrottype. "The members of the society," says Mr. Spencer, alluding to the Liverpool Polytechnic Society, at a meeting of which the paper was read, "will recollect that on the first evening it met,



I read a paper on the 'Production of Metallic Veins in the Crust of the Earth,' and that among other specimens of cupreous crystallization which I produced on that occasion, I exhibited three coins; one wholly covered with metallic crystals, the other on one side only. It was used under the following circumstances:—When about to make another experiment, and being desirous of using the piece of wire used in the first instance, I pulled it off from the coin to which it was attached. In doing this, a piece of the deposited copper came off with it; on examining the under portion of which, I found it contained an exact mould of a part of the head and letters of the coin, as smooth and sharp in every respect as the original on which it was deposited."

22. We learn, by the preceding extract, that Mr. Spencer was experimenting with a voltaic arrangement similar to that of Professor Daniell; and that, on detaching the precipitated copper, he found, as that gentleman and others had done, that every impresssion was transferred to the precipitated copper. It is true, accident presented the fact to him in a much more forcible form than that in which it had been presented to others; the want of a proper piece of copper to complete the arrangement, occasioned Mr. S. to introduce a penny as a substitute, and, on detaching the precipitated copper, he found the head and letters distinctly marked upon it, so that a fac simile of the coin was produced; and this new application of the voltaic battery presented to him in a manner so forcible that it was impossible to neglect it. Mr. Spencer pursued the subject, and so far succeeded in his experiments as to be able to furnish processes by which medals and plates may be copied, and some non-conducting substances coated with copper.

23. The letter of Mr. Jordan in the *Mechanics' Magazine* attracted so little attention, that it had been overlooked; and probably would have remained unknown, had not Mr. Dircks, of Manchester, called attention to it in a recent

number\* of that journal. It will be observed that Mr. Jordan anticipated all the most important parts of Mr. Spencer's communication, and must now take the position so long occupied by Mr. Spencer—that of the author of the earliest successful application of electricity to the arts.

24. In studying the history of the art of electro-metallurgy, it should be borne in mind that the individual who will eventually be regarded as the originator of the art, cannot claim to be ranked as a discoverer;—the art in question consists of the application of facts, already matters of notoriety, to some useful or ornamental purpose. The announcements of Mr. Jordan and Mr. Spencer contain no discovery, so far as obtaining impressions by galvanism is concerned, for the announcements of De la Rue and others contain every fact which those gentlemen pointed out; but while the philosophers contented themselves with noticing the exactness of the impression produced by voltaic precipitation, even to the “polish” and counterpart of “every scratch,” the printer and the carver and gilder apply themselves to the production of impressions of printers' type and medals by the same action. To them, then, belongs the merit, usually reserved for practical men; that of applying facts which had hitherto been unapplied; of creating a new, beautiful and valuable art from materials until then neglected, although within the reach of all.

25. The position which Mr. Spencer has so long occupied, as the earliest English experimenter in this art, and which now clearly belongs to Mr. Jordan, cannot but excite the surprise of all who are interested in this art. It is surprising that the letter of Mr. Jordan to the *Mechanics' Magazine* should have been so long overlooked, and still more surprising that Mr. Jordan should have permitted the honour with which the origin of so important an art is associated to be appro-

\* No. 1069, Feb. 1844.

priated by another. The supineness of Mr. Jordan is equalled by that of his friends, for it now appears that his claim to the origin of the art of electro-metallurgy was known to many individuals.

26. Besides the names of Mr. Jordan and Mr. Spencer, several names new to the history of electro-metallurgy are introduced by Mr. Dircks, in the paper already referred to. Mr. Bessemer is mentioned as having precipitated crystalline copper on lead castings more than ten years ago. Mr. John Dancer, of Manchester, also produced a design by attaching paper to a metallic plate and depositing copper thereon; the deposit was formed only on those parts which were not covered by paper, so that on tearing off the precipitated copper, the design was cut out, as it were, of the precipitated sheet of copper. Mr. Dancer also produced designs by impressing his name on a copperplate, and depositing copper on the indented plate.

27. There can be little doubt that the precipitation of metals by voltaic agency, particularly on the large scale on which this phenomenon presents itself in the constant battery, has suggested to many individuals the possibility of the useful application of the voltaic battery to the arts, although but few have published their views respecting such application. It has been demonstrated to the author of this treatise, on the most conclusive evidence, both documentary and personal, that the late Mr. Woolrich, of Birmingham, succeeded in applying coatings of copper to various articles by means of the voltaic battery; and that, in one instance at least, he succeeded in gilding an article by voltaic precipitation from the ammoniacal solution of gold, before the published experiments of Mr. Jordan and Mr. Spencer appeared. Mr. Woolrich, however, never published an account of his experiments, as, from the imperfect nature of the voltaic batteries then in use, the deposition of copper was considered too troublesome to be valuable; and, from the same cause, he was unable to



repeat his experiments on gilding. There are, no doubt, many individuals who similarly experimented, but the historian has only to do with published experiments; and the present instances are only adduced to show that voltaic precipitations were so strikingly brought before experimenters in electrical science, that it would have been impossible for them to have been much longer neglected.

28. Since the experiments of Jacobi, Jordan and Spencer, many individuals have contributed to the perfection of the art of electro-metallurgy. Among those whose labours have advanced the art to its present state, must be particularly mentioned the names of Mason, Murray, Smee, Elkington and Woolrich.

29. To Mr. Mason the art is indebted for the suggestion of an arrangement of the electro-metallurgical apparatus more completely under controul than that of Mr. Spencer, and which led to the introduction of the voltaic battery in electro-metallurgical operations as a separate and independent source of electricity, instead of making the surface on which the deposit was taking place a part of the electrical apparatus, as had been done by previous experimenters. Mr. Murray contributed the first completely successful process for causing a deposit to take place on non-metallic surfaces. Mr. Smee has experimented extensively, and with much success, on the circumstances under which the various metals may be deposited from their solutions. Mr. Elkington discovered a class of salts from which gold and silver may be precipitated with much greater success than from any previously known; and Mr. Woolrich has succeeded in applying the magneto-electric current to the reduction of metals, a discovery which promises to be of greater importance than any with which the art has hitherto been enriched.

## CHAP. II.

CHEMISTRY AND ELECTRICITY AS CONNECTED WITH  
ELECTRO-METALLURGY.

30. A GENERAL knowledge of the laws of chemistry and the allied sciences, is essential to the successful practice of electro-metallurgy ; every process in the art is a chemical or an electrical process, determined by conditions and controuled by forces, the study of which constitutes the science of chemistry.

31. Every natural object with which we are at present acquainted, whatever its origin, whether animal, vegetable or mineral ; whatever its physical condition, whether solid, liquid or gaseous, and whatever its physical properties, consists of one of the bodies enumerated in the following table, or is a compound of two or more of them. These bodies are called elements, because they cannot be decomposed or resolved into other simpler forms of matter, and they are hence supposed to be the ultimate bodies or elements, of which material objects are composed.

## (32.) TABLE OF ELEMENTS

WITH THEIR EQUIVALENT NUMBERS OR COMBINING PROPORTIONS.

Oxygen . . . . .	8.01	Sodium . . . . .	23.31
Hydrogen . . . . .	1.	Lithium . . . . .	6.44
Nitrogen . . . . .	14.19	Barium . . . . .	68.66
Carbon . . . . .	6.	Strontium . . . . .	43.85
Sulphur . . . . .	16.12	Calcium . . . . .	20.52
Selenium . . . . .	39.63	Magnesium . . . . .	12.69
Phosphorus . . . . .	31.44	Aluminum . . . . .	13.72
Boron . . . . .	10.91	Glucinum . . . . .	26.54
Silicon . . . . .	22.22	Zirconium . . . . .	33.67
Chlorine . . . . .	35.47	Thorium . . . . .	59.83
Iodine . . . . .	126.57	Yttrium . . . . .	32.25
Bromine . . . . .	78.39	Manganese . . . . .	27.72
Fluorine . . . . .	18.74	Iron . . . . .	27.18
Potassium . . . . .	39.26	Zinc . . . . .	32.31

Cadmium . . . . .	55.83	Molybdenum . . . . .	47.96
Cobalt . . . . .	29.57	Tungsten . . . . .	94.8
Nickel . . . . .	29.62	Columbium . . . . .	184.9
Copper . . . . .	31.71	Tellurium . . . . .	64.25
Bismuth . . . . .	71.07	Titanium . . . . .	24.33
Lead . . . . .	103.73	Osmium . . . . .	99.72
Tin . . . . .	58.92	Mercury . . . . .	101.43
Cerium . . . . .	46.05	Silver . . . . .	108.3
Uranium . . . . .	217.26	Gold . . . . .	199.21
Arsenic . . . . .	75.34	Platinum . . . . .	98.84
Antimony . . . . .	129.24	Palladium . . . . .	53.36
Chromium . . . . .	28.19	Rhodium . . . . .	52.2
Vanadium . . . . .	68.66	Iridium . . . . .	98.84

33. These elementary bodies are rarely found in nature uncombined. When presented to each other under certain conditions, they enter into combination so as to form compounds, which are generally possessed of physical characters very dissimilar to those of their constituent elements. The force by the operation of which the elements of a compound are, in the first instance, made to combine, and by which they are afterwards held together, is called chemical affinity. It is essentially distinct from the other attractions or affinities, as gravitation and magnetism; these produce changes only of a physical character: whereas, chemical affinity produces changes only in the chemical or elementary constitution of bodies; and the physical changes it commonly effects, are secondary or indirect consequences of its action.

34. These elements combine only in certain proportions;—that is to say, on presenting together two elements which have an affinity for each other, a combination is formed, in which the quantities of the elements have a certain relation. The proportions in which any two elements combine with each other, are the same as those in which either of these elements combines with a third; and further, if any two elements combine together, in two or more different proportions, so as to form two or more different compounds, the quantities in the several compounds have a very simple relation to each other.

35. Suppose four elements, A, B, C, D, to be capable of combining together so as to form a variety of compounds;—



and suppose, further, that one part by weight of A, combines with two parts of B, to form a compound, with three of C to form another, and with four of D to form a third. Now, it is found that these numbers not only represent the proportions in which these bodies combine with A, but also the proportions in which they combine with each other. For example, if there exist a compound formed by the union of B and C, the proportions of those elements will be represented by the numbers above associated with them,—namely, two of the former and three of the latter, or some multiple of those numbers. Further, the proportion of any one of these elements represented by its number, is chemically equivalent to the proportion of either of the other elements represented by its number: thus, if a compound consisting of three parts of C, and four of D, be decomposed by the addition of the element A, the proportion of this last element requisite for such decomposition is represented by 1, which will combine with 3 of C, or 4 of D, and by that combination will liberate 3 of the former, or 4 of the latter, as the case may be. It is evident, then, that 1 of A is equal to—inasmuch as it takes the place of—4 of D or 3 of C in a chemical compound, and *vice versâ*. These combining numbers of the various elementary bodies, are called their chemical equivalents, and are the numbers placed opposite to them in the table.

36. If we consider with chemists generally, that matter exists in the form of atoms,—that is to say, minute, indivisible, unalterable particles, then the equivalent numbers of the elements represent the relative weights of their atoms.

37. Many remarkable and interesting relations present themselves in studying the laws of chemical combination; but it is only to those laws of combination, and those compounds, which have immediate reference to electro-metallurgy, that attention will be here directed. Electro-metallurgy is an art by which metals are reduced from their

soluble compounds, by the agency of electricity; these compounds are called salts, and their constitution must be briefly studied.

38. There are two classes of salts. In one class the metal is directly combined with an electro-negative body, and thus only two elements enter into its composition. For example, chlorine and copper combine to form a salt called chloride of copper. In the other class each of the constituent elements of the salt is a compound; thus, sulphate of copper consists of sulphuric acid and oxide of copper—the sulphuric acid is a compound of sulphur and oxygen, and the oxide of copper, of copper and oxygen.

39. It will be observed that, in the first named salt (chloride of copper), a simple body or element is combined with a simple body; while, in the other (sulphate of copper), a compound combines with a compound; and it was formerly thought by chemists that this law was general,—that is to say, that elements can only combine with elements, and compounds with compounds. Such an opinion is no longer entertained; for it is now known, with certainty, that in several cases this law does not obtain, and the opinion that it has no foundation whatever in nature, is fast gaining ground.

40. When two elements combine together in the least proportions, the simplest state in which we can conceive of their connection, is that of an atom of one directly associated with an atom of the other (36); and there is no reason why we should suppose any other method of combination: but when one of the elements in a compound is not in its least proportion, we may suppose the bodies to be grouped together in two ways. We may either suppose that one atom (36) of one of the elements is directly combined with two atoms of the other; or we may suppose that a compound is first formed between the elements, consisting of one atom of each, and that this compound is combined with the second atom of the element in greatest quantity. On this latter

supposition we admit the combination of an element with a compound, in opposition to the view which supposes that elements can only combine with elements. (39.)

41. If we adopt this view (and there are powerful reasons for believing it to be the correct one) we may regard the salts as all similarly constituted. Sulphate of copper, which is formed by adding sulphuric acid to oxide of copper, is not to be regarded as a compound, in which the acid and oxide still exist; but we may suppose it to be a direct compound of the metal, copper, with a radical,\* composed of sulphuric acid and oxygen;—we may suppose that, on adding sulphuric acid to oxide of copper, the oxide first suffers decomposition, by yielding its oxygen to the sulphuric acid, to form the radical in question, and that this compound immediately combines with the liberated metal. This hypothetical compound radical, whose composition is that of sulphuric acid with an additional equivalent of oxygen, may be called sulphat-oxygen; and the salt, instead of being called sulphate of copper, should, in conformity with this view, be called sulphat-oxide of copper.

42. These considerations have an important bearing on the theory of electro-metallurgical processes; for, on the latter view, the deposition of a metal is owing to the resolution of a salt into its compound radical and the metal; while, in the former view, the deposition of a metal must be regarded as a secondary result, brought about by the decomposition of the water in which the salt is dissolved. The importance of these considerations will be more evident in studying the decomposition of salts by the electric current.

43. Electricity is an agent intimately allied to, if not identical with, chemical affinity. (33.) Of its ultimate nature, as of that of every other natural agent, we know literally

\* A radical is a body which, though compound, acts the part of an element. Thus cyanogen, a compound of carbon and nitrogen, combines with potassium, sodium, &c.



nothing; nor does our knowledge of its effects enable us even to frame a consistent theory. By some philosophers it is considered as a fluid, subtle in the highest degree,—pervading every species of matter,—unrecognised when quiescent, and developing itself in the various forms before spoken of, when, by the arrangement of the necessary conditions, it is set in circulation. Others, again, have been led by its effects to consider it as a compound fluid, which only puts forth its extraordinary powers when decomposed; that this decomposition takes place in the voltaic battery, and other electrical machines; and that these fluids circulate through those instruments in contrary directions. Other philosophers have rejected the idea of circulation: they regard it as an affection of ordinary matter, or of the hypothetical ether, the vibrations of which, constitute light. Nor are these the only theories that have been framed to connect together the beautiful phenomena of electricity: scarcely a philosopher of distinction can be pointed out who does not entertain views on this subject peculiar to himself. We shall not follow these speculations into detail, but content ourselves with a knowledge of the facts of the science.

44. Electricity may be excited, or set in circulation, in a variety of ways;—by the friction, compression, and rupture of bodies;—by the agency of heat and chemical action;—and by the motion of metals in the vicinity of magnetic bodies.

45. By rubbing resinous and vitreous bodies on dry animal or vegetable matters, they acquire the property of attracting light bodies, and of exhibiting other new and extraordinary properties. On presenting a rounded metallic body, or the knuckle of one of the fingers, to a stick of sealing wax, which has been rubbed with dry flannel, a snapping noise occurs when the knuckle is brought near the wax, arising from the passage between them of a luminous spark, which may be seen by performing the experiment in a dark room. These, and the many other

properties exhibited by the sealing wax, are dependent on the peculiar condition into which it has been brought by friction with the flannel. A body exhibiting such properties is said to be electrical, and the unknown cause of these properties is called electricity.

46. Electricity can be transferred from the body in which it is excited to a second body, and from that to a third, &c. This transference can only take place with certain bodies, which are called conductors, and through the substance of which electricity passes; while another class of bodies, called non-conductors, do not admit of its passage through them. Metals and charcoals are the only true conductors, as it is only through them that it can pass without producing change. In passing through other bodies, such as salts (38), it is only conducted by virtue of the decomposition of the salt, and the quantity of electricity conducted is in strict relation to the quantity of salt decomposed.

47. The quantity of electricity produced by the friction, compression, and rupture of bodies, is too small in quantity to be of any value in electro-metallurgical operations, and recourse must be had, in this art, to the electricity produced by chemical action, by heat, or by magnetism. Electricity may be produced more copiously from these sources than from any other, and they must, therefore, be treated somewhat in detail.

48. If a plate of ordinary zinc be plunged in dilute sulphuric acid, violent effervescence occurs; the oxygen of the water (as will presently be shown) combines with the metal, forming oxide of zinc, which, uniting with the sulphuric acid, forms sulphate of that metal; while the hydrogen, the other element of the water, escaping in the gaseous form, occasions the effervescence observed; eventually, the zinc disappears, and the dilute acid is replaced by a solution of the sulphate of zinc. If, during the time this phenomenon is taking place, a strip of copper be introduced into the

solution, and made to touch the zinc, effervescence also occurs at its surface, by the escape of hydrogen, although it will be found that no chemical action takes place upon the copper. The escape of hydrogen, however, will be much less than at the surface of the zinc.

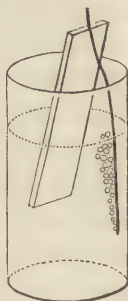
49. Now, inasmuch as the copper has not been chemically acted on, it is evident that the hydrogen appearing at its surface can only result from the decomposition of the water effected by the zinc; and its appearance in such a part of the arrangement is, at first sight, calculated to excite surprise. This circumstance, however, is satisfactorily explained, by the fact, that pure zinc, except when in contact with another metal, is perfectly insoluble in dilute sulphuric acid; and then, although the chemical action takes place entirely at the surface of the zinc, the whole of the hydrogen escapes at the surface of the metal in contact with it. We shall not enquire in this place *why* the hydrogen appears in such a part of the arrangement; it is sufficient to know the fact, to enable us to understand the experiment under consideration.

50. We now perceive, in relation to the preceding experiment, that in reality not an atom of hydrogen presents itself at the true surface of the zinc, but that it is evolved from the particles of foreign metals and charcoal with which the zinc is contaminated, and which are scattered about its surface. In other words, that which takes place on the large scale, when a plate of pure zinc is associated with a plate of copper, and immersed in the acid solution, takes place on a small scale when impure or ordinary zinc is used alone, the surface of that metal presenting almost an infinity of such combinations.

51. In making this experiment, it is not necessary to place the metals in contact under the surface of the liquid; they may be brought in contact at a point external to the



liquid, as shown in the accompanying figure, or may be connected by the interposition of a third piece of metal. *Fig. 1.*



52. This action only takes place during the time that the metals are connected together (either immediately, or by the intervention of a third piece of metal); if they are removed from each other, however small the distance, the evolution of gas ceases. If the plates are allowed to remain in contact, after a considerable time (dependent on the proportions of the ingredients) the effervescence will become less violent, and will eventually cease. (48.) Let us now proceed to analyze the experiment: the zinc weighs considerably less than when introduced; the sulphuric acid is replaced by a solution of the sulphate of zinc; the copper is wholly unaffected; and the gas evolved from the latter metal is found to be hydrogen.

53. An attentive consideration of these results leads us to the conclusion, that the water of the dilute acid has been decomposed; for, as the sulphate of zinc produced is a compound of sulphuric acid and the oxide of zinc, it is evident that oxygen must have been supplied to that metal by the water; and this view is confirmed by the fact, that the hydrogen given off by the copper is in such proportion, that, if combined with the oxygen of the oxide of zinc, water would be the product.

54. In this experiment the enquiry arises,—why do not the oxidation and solution of the zinc take place without the presence of a second metal; and how comes it that the hydrogen, resulting from the decomposition of the water, does not present itself at the surface of the zinc, where it is developed, but passes through the liquid, and is evolved at

the other metal? The question suggests the answer:—the facts, that the metals must be in intimate contact, and both immersed in the same acid,—that the only element set free is carried to a point, at a considerable distance from that at which it is liberated,—demonstrate that the chemical action which takes place is accompanied by the circulation of some extraordinary power, or would seem rather to be dependent on it; for, when, by breaking the contact between the plates, we interrupt its circulation, all chemical action ceases.

55. That some new power is thus called into action, we have abundant evidence. It has already been observed that the plates, instead of being in actual contact, may be connected together by a third piece of metal; nay, if a stout copper wire, a mile long, be employed, and one end of it be made to touch the zinc, and the other the copper, the same phenomena will be presented. Now, the whole length of this connecting wire exhibits some remarkable changes in its physical characters. Before its introduction between the plates of our rude voltaic apparatus, it was perfectly inert with regard to magnetic bodies; but now it attracts iron filings as though it were a magnet; and a compass, or magnetic needle, brought near it, is powerfully deflected. It exhibits, moreover, calorific and chemical phenomena. By making the connection between the plates with a short and very fine wire, a powerful calorific effect will be developed; the wire will glow with the most intense heat; and if the action of the apparatus be sufficiently energetic, will be fused and dissipated in minute globules, or will burn with a brilliant scintillation.

56. Again, let the connection between the plates be made through the solution of some chemical compound, easily decomposed—iodide of potassium, for example—and the elements of that compound will be separated. All these facts demonstrate the operation of some subtle power, which,

from its presence in every part of the arrangement, is believed to circulate through it, and, under the circumstances enumerated, to develop itself in the various forms of magnetism, heat, and light. (55.) That agent is voltaic electricity.

57. The apparatus just now described differs only from the pile of Volta and the other batteries enumerated elsewhere, in consisting of but one pair of plates, while they are formed by the assemblage of several such pairs. The pile or battery is a series of arrangements similar to the one just experimented with, so disposed that the zinc of one cell is connected with the copper of the next, the zinc of that with the copper of a third, and so on, to any extent. Such a form of instrument is called an intensity arrangement, while the single pair of plates is called a quantity arrangement. The different properties of quantity and intensity we will now illustrate.

58. A single voltaic pair, it has already been said, will decompose iodide of potassium; but if the connection between the plates be made with other compounds,—water, for example,—no decomposition of the water will take place; the voltaic current will not pass (for water can only conduct it by suffering decomposition), and, consequently, the battery will be as inactive as though no such connection had been made. If, however, water be made the medium of communication between the ends of a compound battery, consisting of nine or ten pairs, the water will be rapidly decomposed, and the voltaic current will pass, as the escape of hydrogen at the surface of each copper plate of the battery will demonstrate. The single pair is called a quantity arrangement, because it decomposes, with the consumption of a given quantity of zinc and acid, as great an amount of any compound *which it can decompose*, as the other arrangement decomposes, by an equal consumption of materials, in *each* cell of the battery; but there are very few compounds which



may be resolved into their constituent elements by a single pair.

59. A case will, perhaps, make the matter more clear. Suppose we have a battery consisting of ten cells, and that water be made the medium of communication between its extremes, as much water will be decomposed by this instrument as by one of a hundred pairs, supposing them to be similarly circumstanced in every respect. This, at first sight, appears paradoxical; but an examination of the nature of the chemical action in the voltaic battery will remove every difficulty.

60. The annexed diagram, *fig. 2*, represents a single voltaic pair, consisting of a plate of zinc, *a*, and another of copper, *b*, immersed in a vessel of dilute sulphuric acid; a wire from the zinc is con-

*Fig. 2.*



nected with a plate of platinum, *c*, in a second vessel, containing dilute acid; and a wire from the copper is attached to another plate of platinum, *d*, also in the acid solution. It has already been said that a single pair will not decompose water; but in this illustration we will suppose it to possess that power (for, by a slight modification, it may be made to do so), as we prefer that, in this experiment, water should be the compound decomposed. The voltaic current, then, originating at the surface of the zinc, gives rise to the combination of oxygen with that metal; while hydrogen escapes at the surface of the copper; we will suppose the current passing from the copper through its wire to the platinum plate in the second vessel, thence through the liquid to the other platinum plate, and through its wire to the zinc.

61. Now, in tracing the current through the battery, it will be observed that oxygen is that element of the decomposed water which occurs at the surface from which the current

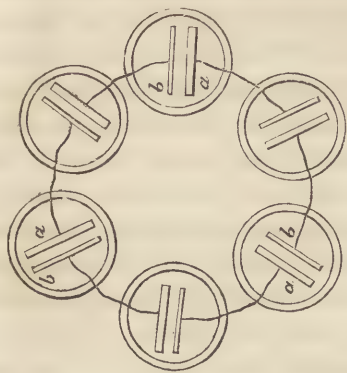
enters the liquid; and that hydrogen, the other element of water, is disengaged at the surface where the current leaves the liquid,—namely, the copper. On examining the decomposition in the second cell, precisely the same thing occurs;—oxygen is liberated at the surface of that platinum plate connected with the copper, and at which the current enters, and hydrogen at the other plate, or that surface where the current leaves the liquid; nay, further, the quantity of water decomposed in the second cell is exactly equal to the quantity decomposed in the battery; the hydrogen is equal in volume to that given off in the battery, and the oxygen equal to that which has combined with the zinc.

62. We must here repeat, that we have assumed, for the purpose of explanation, that which is not strictly correct; inasmuch as a single cell will not decompose water, except under circumstances which we have not introduced into the experiment: but other substances may be decomposed by such an apparatus, and the results are in perfect accordance with what has been said: an amount of such compound will be decomposed, chemically equivalent to the amount of water decomposed in the battery. Our reason for putting the experiment in the above form is, that no misconception may arise respecting the chemical action of voltaic electricity; for the decomposition of the same compound has been effected both in the battery and in the secondary cell, and the amounts of such decompositions not, as they must have been with dissimilar compounds, relatively, but absolutely the same.

63. We will now proceed to a consideration of the compound battery; and in that instrument we shall have a further confirmation of the view we have been endeavouring to enforce, *i.e.*, that the voltaic current, in passing through any solution, effects the same amount of decomposition as is effected in the battery itself.

64. The annexed diagram, *fig. 3*, will serve to illustrate the

*Fig. 3.*



nature of the compound battery,—to explain the cause of the intensity of such a modification,—and to reconcile the apparent anomaly, that such an arrangement evolves a current no greater in quantity than that generated in any one of its cells. The apparatus represented consists of a series of cells, each containing a plate of

zinc, *a*, and another of copper, *b*, immersed in dilute sulphuric acid; the zinc of one cell being joined to the copper of the next. An apparatus, arranged as the above, would be extremely active; the evolution of hydrogen would be very copious, and the zinc would rapidly dissolve, for there is no obstruction to the passage of the voltaic current.

65. To begin our illustration, let the reader imagine, in the first instance, that only one of the cells of this compound battery is in action; it is immaterial which is selected; the current of electricity generated in that cell has to pass through each of the others; and, as we have before shown (60), in passing through the dilute acid, the water of that acid will be decomposed, oxygen will be developed at the surfaces where the current enters, and hydrogen at the surfaces where it leaves the solution; so that this current, supposing it capable of passing through a hundred such cells, would decompose in each as much water as was decomposed in the battery. Now, this current meets no obstruction whatever in passing through the arrangement described; on the contrary, it acquires an additional impulse at every cell, for each one, being precisely similar to that from which the current was supposed to originate, is equally favourable to



the passage of a voltaic current ; and hence the current is accompanied by a given amount of chemical action in its passage through each cell, and acquires thereby additional intensity. In other words, each cell of a compound battery is a decomposition cell, in which the materials are so arranged that, instead of obstructing the passage of the current, there is a disposition to the generation of one.

66. The reader will now perceive the cause of the intensity of the compound battery, and, recollecting that the same current effects the decomposition in each cell, will no longer be surprised that the quantity of electricity in a compound battery is no greater than that of one of its cells.

67. If any one of the wires connecting the plates of the last described apparatus be severed, and the cells be ranged in a straight line instead of a circle, it will immediately be recognised as the *couronne des tasses* of Volta, described in another part of this treatise ; the wires which now constitute the ends of the apparatus, have been very inappropriately termed the poles of the battery. After what has been said, it is hardly necessary to remark that, by plunging them in water, the circuit being again completed, the action of the battery recommences, and the water will be decomposed.

68. It was formerly believed that the decomposing power of the voltaic battery was owing to an attraction existing between these wires and the elements of the compound ; it is evident that such a view is incompatible with the present state of science ; still, however, the terminal wires of a battery are called the positive and negative poles. Many attempts have been made to introduce less objectionable names, but they have been only partially successful. It was proposed by Faraday to call them electrodes, or passages for the electricity ; the one being distinguished as the *anode* and the other as the *cathode*, in reference to the presumed direction of the current. It has also been advised to call

them the zincode and platinode ; and a third party has named them oxode and hydrode.

69. The reader will bear in mind that the words negative pole, cathode, and platinode are synonymous, and are employed to designate the plate or metal, which, considering the decomposition cell as one of the cells of the battery, holds the place of the copper, silver, or platinum ; and that the positive pole, anode, zincode, or oxode is that at which oxygen, acids, &c., appear, and corresponds to the zinc of the battery.

70. There are other circumstances connected with the decompositions effected by electricity, which must be noticed in this place. No solid can suffer decomposition in the voltaic circuit ; nor can any liquid, excepting such as conduct ; and in them conduction and decomposition are, with few exceptions, inseparable. For example, chloride of silver is, at ordinary temperatures, a solid ; and in that state resists decomposition by the most powerful apparatus : by the application of heat, this compound fuses, and in that state conducts the current even of the feeblest voltaic arrangement, and, at the same time, suffers decomposition. Water affords an illustration still more striking. In its ordinary, or fluid, state, it is decomposed by a current of moderate intensity ; but when frozen the utmost intensity will not effect the separation of its elements ; for in such a state it does not conduct the voltaic current. If one of the platinum plates in the apparatus be coated with the thinnest film of ice, the current will be completely arrested.

71. There are apparent exceptions to both these laws. Experiments have been adduced in which compounds, in the solid state, appear to have been decomposed, and in which liquids have conducted without decomposition.

72. Many of the changes which occur in the voltaic circuit are due to what is called secondary action. In the case of aqueous solutions, many of the decompositions may be traced

to the action of the oxygen and hydrogen, evolved by the passage of the current through the water, and are independent of the voltaic power. The direct action of the voltaic current is very limited, as only compounds of a particular constitution are susceptible of such decomposition; and this constitution not with relation to the elements, but the proportion of those elements; for of two compounds, formed of the same elements, one may suffer, and the other resist, decomposition.

73. Only those compounds consisting of one equivalent or proportion of each element are affected by the voltaic current. It is not, however, essential that the elements should be simple, undecomposable bodies; for a body, the constituents of which are compound, suffers decomposition, or is resolved into those proximate elements; and these proximate elements themselves may even be so constituted as not to yield up their component parts in the voltaic circuit. Examples will impress this law upon the memory. Water is a compound of one atom or proportion of each of its elements, and, consequently, in accordance with the law above stated, is decomposed by the voltaic battery. But any compound of the same elements in a different proportion would not suffer decomposition. If there were a compound of two atoms of hydrogen and one of oxygen, it would not be affected by voltaic electricity. And so with those substances whose constituent parts are compounds; in order to suffer decomposition by the voltaic current, they must consist of one equivalent, or proportion (35), of each of their component elements. Sulphate of copper, for example, is resolved into sulphuric acid and oxide of copper; though the sulphuric acid will not, under similar circumstances, be decomposed, for it is not a binary compound; nor will oxide of copper, because it is a solid.\*

\* The chemical reader need not be reminded that, in this treatise, the equivalent of hydrogen, and the composition of water, as given by British chemists, are assumed, in opposition to the views of continental authorities. The assumption



74. From what has been said respecting the constitution of salts (40), it is evident that, if the theory which assumes the direct combination of a metal with a compound radical, be the true theory, their decomposition in the voltaic circuit, is a direct or primary effect; and it is equally evident, that it is a secondary effect, if salts are constituted of an acid combined with an oxide.

75. By adopting the new theory, the appearance of metal at the negative electrode, and acid combined with an additional equivalent of oxygen (41) at the other, is at once accounted for; but, if the old theory be adopted, it is necessary to assume the decomposition of water, and to attribute the decomposition of the salt to the nascent hydrogen of the decomposed water; for, according to the law of voltaic decompositions (73), the direct effect of the current is to resolve the salt, on this theory, into a metallic oxide and an acid. Instead, therefore, of assuming the decomposition of the salt, the water in which it is dissolved is believed to be decomposed; and the decomposition of the salt is accounted for, by supposing the hydrogen of the water to combine with the oxygen of the metallic oxide, whereby metal is liberated and acid set free; while the oxygen of the water is liberated at the other electrode.

has only been made on the ground of convenience, and no remarks in a treatise like the present, can have reference to so important a question.

## CHAP. III.

ON THE VOLTAIC BATTERY.

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76. THE science of Voltaic Electricity originated in an experiment made by Galvani in the year 1790. He observed that, on placing a recently killed animal upon a plate of zinc, and touching it with a wire or plate of copper, also in contact with the zinc, violent contractions of the muscles of the animal immediately occurred. Although it was this experiment that determined the masterly researches of Volta, and from which the science must date its origin, yet an analogous fact was known long prior to Galvani's discovery. It had been announced, in an obscure German work, entitled "The General Theory of Pleasures," that if a plate of zinc were placed upon the tongue, and a piece of silver under it, a strange taste would be observed each time the edges of the pieces of metal were brought in contact. This experiment, however, attracted no attention, and cannot be said to have any connection with the progress of our science.

77. In repeating the experiments of Galvani, Volta was led to the construction of an instrument, which, in honour of its illustrious inventor, is called the voltaic pile. This instrument consists of a series of plates of dissimilar metals, usually copper and zinc; these, to the extent of forty or fifty, are piled upon each other in regular succession, a piece of card or flannel, wetted with a saline or acid solution, being interposed

between the metals of each pair. It is represented in *fig. 4*,

*Fig. 4.* where *a* is the plate of zinc, *b* the plate of copper, and *c* the moistened flannel. It was found that the effects of this instrument were much more powerful than those of a single pair of plates, and that it exhibited a series of new and extraordinary phenomena. If the moistened hands were brought in contact with the ends of such a pile, a distinct shock would be felt; and the leaves of gold-leaf electrometers similarly situated were observed to diverge. By connecting wires to the ends of this instrument, and plunging them in water, minute

bubbles of gaseous matter escape from them: on examination, these bubbles are found to consist of oxygen and hydrogen, the gaseous constituents of water. The wires thus connected to the ends of the pile are called its poles; and by them the effects of the instrument could be transmitted to almost any distance. The cause of the phenomena exhibited by the pile of Volta has been already explained. (54.)

78. The plates of zinc in this and other batteries, are called the positive plates, because the whole of the chemical action is confined to them. The copper or silver plates are called the negative plates. The arrangement of the elements exhibited in *fig. 4* is, in many respects, inconvenient; and Volta contrived another arrangement, which he called

*Fig. 5.*

the *couronne des tasses* (see *fig. 5*).



This instrument consists of any number of vessels

containing the acid solution, and an equal number of bars of zinc *a* and silver *b* soldered end to end, and so bent that, while the zinc bar rests in one of the vessels, the slip of silver soldered to it hangs in the other. This arrangement is decidedly superior to the pile; and it is worthy of remark,



that the voltaic batteries of the present day scarcely differ from this modification.

79. The next alteration in the voltaic apparatus was made by Mr. Cruikshanks—(*fig. 6*).

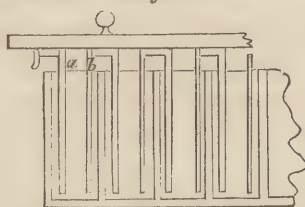
*Fig. 6.*



The plates in his battery were square, and the copper *a* and zinc *b* of each pair were soldered together. These com-

pound plates were cemented in grooves cut transversely in a wooden trough, and themselves formed a series of compartments for holding the exciting liquid. In using this instrument, the dilute sulphuric acid was poured into the trough, which was so inclined that each compartment became filled with an equal quantity of the liquid. This instrument possesses many inconveniences: if the plates are situated at a great distance from each other, the action is impeded; and if, to remove this objection, the plates are placed near each other, the cells are too diminutive to hold the requisite quantity of acid. The impossibility of removing the zinc plates for the purpose of cleaning them, is also a serious

*Fig. 7.*



objection. These inconveniences suggested the modification, called Babbington's battery—(*fig. 7*). This consists of an earthenware trough, divided into a number of compartments, in each of which is placed a plate of zinc *a*, and

near that, a plate of copper *b*, the zinc of one cell being connected with the copper of the next. The series is suspended from a bar of wood. This battery, like the former, is excited by dilute sulphuric acid: its superiority consists in the facilities afforded for removing the zinc plates, and in the close approximation of the metals—points of great importance. It was by an instrument of this kind that the splendid experiments of Davy were performed.

80. The next improvement was introduced by Dr. Wollaston. He completely surrounded the zinc with the copper—an alteration which was found to increase the amount of available power, to nearly double that, previously obtained from an equal extent of zinc surface. The improvement which comes next in order is, perhaps, the most important one that has yet been introduced; it is the amalgamation of the surfaces of the zinc plates by mercury. For this valuable contribution we are indebted to the late Mr. Kemp.

81. It has already been stated (49) that when impure zinc is used in voltaic experiments, the impurities (such as minute portions of charcoal and foreign metals) with which the zinc is contaminated form an infinity of galvanic circles, by virtue of which the metal dissolves. Hence, when ordinary zinc is introduced into dilute sulphuric acid, it dissolves rapidly; and its solution is accompanied with violent effervescence, occasioned by the escape of hydrogen. Now, the voltaic electricity, with which the solution of the zinc is accompanied, is, in this case, confined to such minute circles that we cannot divert it into a new channel, so as to make it subservient to our purpose; and, as the whole of the zinc dissolved, and acid saturated, yield no current, this local action, as it is called, occasions much waste in the materials of the battery. The improvement in question completely destroys this local action.

82. By using pure zinc in the construction of voltaic batteries, the whole of the chemical action is turned to account; not a particle of zinc is dissolved, but it renders, in an available form, that amount of voltaic electricity which is necessarily associated with such solution, but which, as already explained, with the ordinary metal, is evolved under circumstances which render it useless. (79.) The use of pure zinc in the construction of voltaic batteries would be attended with such expense, as to completely prevent its

introduction; indeed, the improvement in the voltaic battery now under consideration (the amalgamation of the zinc) renders its use unnecessary.

83. Many experiments had been made by Sir H. Davy, and others, on amalgamated zinc; but for its introduction into the voltaic battery we are indebted, as before stated, to Mr. Kemp. Zinc, the surface of which is amalgamated or covered with quicksilver, is, like pure zinc, insoluble in dilute sulphuric acid, unless in contact with another metal; in short, plates of amalgamated zinc conduct themselves in every respect like plates of pure zinc; and what has been said of the pure metal applies to that which is impure, when its surface is amalgamated. Many explanations have been given of the action of the mercury; but as most of these are, more or less, unsatisfactory, we shall not enumerate them, but content ourselves with a knowledge of the facts.

84. Zinc is very easily amalgamated. It is only necessary to immerse it for a few moments in dilute sulphuric acid, in order to clean its surface. If it now be plunged into mercury, it will be found to acquire a perfect coating of that metal; or the mercury may be poured on the zinc, and spread about by a rag or hare's foot—a more economical and equally effective plan.

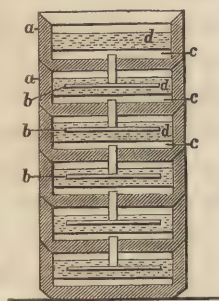
85. The battery now commonly employed in electro-metalurgical operations consists of rods or plates of amalgamated zinc; these are surrounded with plates of copper brought as near the zinc as possible, without incurring the risk of touching. The compound plates are immersed in jars, containing a mixture of one part of sulphuric acid or oil of vitriol, and eight or nine parts of water.

86. The form of battery recommended by Mr. Kemp differs materially from all those hitherto described; the amalgam of zinc and mercury is in a fluid form, and is contained in a series of wooden troughs or trays, piled on each other like the plates in Volta's pile. Dilute sulphuric acid is poured in



each tray; and a plate of copper immersed in each, in a horizontal position, is connected with the amalgam of the

Fig. 8.



cell above it, by a rod of copper soldered to the plate, passing through the bottom of the tray, and entering the amalgam. The battery is represented in *fig. 8*:—*a a* are the wooden trays, and *b b* the plates of copper; the amalgam in each tray is represented by *c c*; *d d* represent the several portions of dilute acid in the trays. The copper plates *b b* should be perforated, in order to allow of the escape of the hydrogen.

87. Theoretically considered, this battery is perfect; but in practice, the fluidity of the amalgam is objectionable, inasmuch as in moving the battery about, there is danger of its contact with the copper or negative element; besides, the still greater inconvenience of the various cells being hidden, and the difficulty of rectifying any derangement of the lower cells, without removing the upper ones.

88. These difficulties are, however, purely mechanical, and are wholly obviated by arranging the series horizontally, instead of vertically. This battery, moreover, is very economical; for whilst in all other forms of battery, the plates of zinc require to be amalgamated several times before they are worn out, and eventually become so brittle as to break while of considerable thickness, and hence, occasion the loss both of the zinc and mercury; all that is necessary in this battery, is to add pieces of ordinary zinc from time to time, to the fluid amalgam; the mercury is never lost, and the zinc is not wasted.

89. The battery proposed by Mr. Kemp has never come into general use, as experimentalists have generally preferred

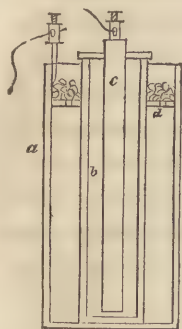
the amalgamated plates ; but there is little doubt, that it will be eventually adopted by those, who, using the voltaic battery as an instrument of art, are desirous of employing the most economical arrangement.

90. Long prior to the invention of Professor Daniell (which comes next in order) it was known that, by increasing the size of the negative plate of the battery, there was a considerable increase in the quantity of electricity generated. The reader will recollect that Dr. Wollaston's improvement consisted in surrounding the zinc with copper, and that that instrument was superior to those in which a less surface of negative metal was used ; but there is obviously a limit to this extension of the negative plate ; for, by enlarging it, its distance from the zinc becomes necessarily greater, and its object is thereby defeated ; for with a negative plate of a given size, it will be found that the evolution of hydrogen rapidly diminishes as it is made to recede from the zinc, and *vice versâ*. However large the negative plate is made—when in action, it is, virtually, exceedingly small ; as we have already seen, the moment the action of the battery commences, the negative plate becomes covered with bubbles of hydrogen, and the parts so coated, being defended from the liquid, are for the time inactive ; hence the extent of metal, which is in constant contact with the liquid, is much diminished by this evolution of hydrogen.

91. This defect is completely remedied by the arrangement of battery devised by Professor Daniell, and called by him the "constant battery." The essential principle in this instrument, is the placing of a solution of sulphate of copper, in contact with the copper of the battery, whereby the hydrogen presented at that surface, is made, while in its nascent state, to enter into chemical union with the oxygen of the sulphate of copper ; and by the suppression of the hydrogen, a large and constant extent of negative surface, is exposed to the zinc. A single cell of the constant battery, is represented in

section in *fig 9*. It consists of an outer cylindrical copper

*Fig. 9.*



vessel *a*, of about three inches diameter, and of any convenient height; in the axis of this cylinder is placed a cylindrical vessel of porous or unglazed earthenware *b*; and in this porous vessel is suspended, a rod or cylinder of amalgamated zinc *c*; dilute sulphuric acid, is placed in the interior or porous vessel, and a saturated solution of sulphate of copper in the exterior, or copper vessel. Crystals of the sulphate of copper, to keep the solution

always saturated, are laid upon a perforated shelf *d*, fixed in the upper part of the cylinder.

92. The action of the sulphuric acid on the zinc, has been already explained (53); and as the use of the porous cell is simply to prevent the mixture of the two solutions, by interposing between them a substance which will not materially interfere with the passage of an electric current, we may altogether dismiss it in considering the phenomena which take place. The hydrogen, then, passes freely to the copper cylinder or negative plate, and is there liberated; on coming in contact, while in its nascent state with the metallic solution, it decomposes that solution; it combines with the oxygen of the metallic salt, and liberates the metal. The copper, thus precipitated, attaches itself closely to the copper cylinder, in which the solution is contained; and this cylinder constantly increases in thickness during the action of the battery by the accumulation of the deposited copper.

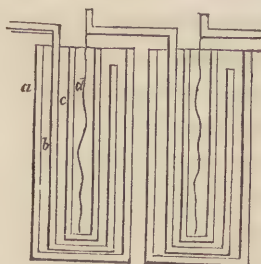
93. By the means now described, the evolution of hydrogen at the surface of the negative metal, which has been shown to be so disadvantageous, is completely suppressed; and by the copper or negative surface being separated from the solution of sulphate of zinc formed in the interior vessel, the reduction of zinc upon the negative metal, which occasions a diminution of power in the ordinary battery, is completely avoided.



94. This voltaic arrangement produces a current of greater intensity than any previously invented; added to which, it possesses the valuable property of extreme uniformity of action—insomuch that it yields a current of invariable intensity, for many hours. We must not, however, omit to mention the disadvantages which are peculiar to it. The expense of the salt of copper renders it less economical than other forms of battery; the porous cells are liable to break after use by the crystallization of the saline matter contained in their pores, and from which repeated washings scarcely suffice to free them. A very small extent of zinc surface is exposed; and as the instrument is inactive until the solutions have penetrated the porous cell, it requires longer time to bring it into active operation, than most of the other forms of battery. We repeat, however, that it has valuable properties not possessed by any other instrument.

95. Subsequent to the battery of Professor Daniell is that of Mr. Grove—an instrument which far surpasses all that preceded it, in point of intensity. In principle it is precisely similar to that of Professor Daniell; Mr. Grove appears, however, to have arrived at its construction, by considerations independent of those which led to the invention of the constant battery; the hydrogen is suppressed at the negative plate by being presented to concentrated nitric acid; and, in order that the acid may have no action on that plate, Mr. Grove uses platinum. It is hardly necessary to remark, that the hydrogen decomposes the nitric acid by combining with its oxygen.

*Fig. 10.*



*Fig. 10* is a sectional representation of two cells of Grove's battery; *a* is the outer cell of glazed earthenware; *b* a plate of zinc bent into the form represented; *c* a vessel of unglazed earthenware; *d* the plate of platinum. The vessel *a*, is charged with dilute sulphuric acid, in the proportion of one of concentrated acid,

to seven of water; the vessel *c*, is filled with concentrated nitric acid. The advantages attendant on this battery, are its extreme activity, and the intensity of the current generated; a single cell of this arrangement decomposes water, and a battery of three or four cells, possesses intensity enough, for all ordinary purposes; the disadvantages under which it labours are, that its power is transient, and that the evolution of nitrous fumes, renders it exceedingly offensive. The expense of the nitric acid is also an objection.

96. From what has been previously said respecting the intensity of voltaic batteries, the reader will, perhaps, be somewhat surprised at the remark, that Daniell's battery possesses a greater intensity, than is produced by a simple acid battery, and that a single pair of plates, arranged on Grove's principle, will decompose water. It is nevertheless true, that the intensity of a single pair of voltaic elements, is increased in a surprising degree by the application, either of the solution of the sulphate of copper, or concentrated nitric acid, to the negative plate. The following experiment will illustrate this fact:—take a single cell of Grove's battery, and connect the platinum and zinc with two platinum plates, immersed in dilute acid, as shown in *fig. 2*. Let the battery be partly filled with dilute sulphuric acid, and let a quantity of the same be put in the porous cell. No action will take place; the current will not pass through the acid in the second cell, and the water, consequently, will not be decomposed. Without disturbing the arrangement, introduce some concentrated nitric acid into the porous cell, and the platinum plates in the second cell will immediately evolve—the one oxygen, and the other hydrogen—and these gases will continue to be given off, until all the nitric acid in the battery, has been decomposed by the hydrogen evolved in it—demonstrating, that the current has, by the introduction of the nitric acid, acquired an intensity, much greater than it previously had.

97. It is by no means easy to understand the cause of this

intensity; the most plausible theory which has been proposed is, perhaps, the following:—the intensity of the current in the simple acid battery may be represented by the attraction of the oxygen of the water, for the zinc; in Daniell's battery, the attraction of the oxygen for the zinc, plus the attraction of the hydrogen for the oxygen of the oxide of copper, minus the attraction of that oxygen for the metallic copper with which it is combined; and in Grove's battery, the intensity will be represented, by the attraction of the oxygen of the water, for the zinc; plus, the attraction of the hydrogen at the negative plate, for the oxygen of the nitric acid, minus, the attraction of that oxygen, for the nitrogen with which it is combined.

98. If we adopt that view of the constitution of the salts, which has been referred to, in the preceding chapter (41), and by which they are all regarded as similarly constituted, the batteries of Mr. Daniell and Mr. Grove, must be differently explained. According to this theory, the sulphate of copper is the sulphat-oxide of that metal; that is to say, a compound of sulphat-oxygen (41) and copper; and its decomposition, and the liberation of metallic copper, a direct, and not according to the old theory, a secondary effect. The acids, too, when combined with water, must be regarded, not as mere solutions, but as definite compounds; dilute sulphuric acid must not be considered as a mere solution of sulphuric acid in water, but as a compound, in which the oxygen of the water is combined with the sulphuric acid, and that compound with hydrogen—in other words, sulphat-oxide of hydrogen. Similarly, nitric acid must be regarded as a salt of hydrogen—the nitrat-oxide of hydrogen, and its decomposition receive a similar explanation.

99. The battery formed by the immersion of a plate of zinc, and a plate of copper in dilute sulphuric acid, receives a simple explanation on the new theory. Instead of referring it to the decomposition of water, and oxidation of the zinc,



and subsequent combination of the oxide with sulphuric acid, we have only to suppose the decomposition of the sulphat-oxide of hydrogen (dilute acid); the zinc, combining with the sulphat-oxygen, and the hydrogen being evolved.

100. The phenomena of voltaic electricity tend to prove the correctness of the new theory of the constitution of salts, but such considerations are too theoretical for discussion in the present treatise.

101. The battery of M. de Moleyns consists of an arrangement exactly similar to that of Mr. Grove, but is excited differently. The external cell containing the zinc is filled with a saturated solution of muriate of ammonia (sal ammoniac); and the internal porous cell in which the platinum is placed, is filled with a solution prepared in the following manner:—Dissolve one pound of nitrate of ammonia in a pint of water; place the vessel containing the solution in a frigorific mixture, and add slowly an equal quantity of concentrated sulphuric acid. Nitric acid is liberated, and is the active ingredient.

102. This battery possesses an intensity equal to that of Mr. Grove's; and the inventor states that its advantages are—the length of time it continues in action; the intensity which it possesses; and, as the zinc plates need not be amalgamated, he claims that as one of its advantages. The last, however, is not peculiar to his battery. The solution of muriate of ammonia (sal-ammoniac) is commonly employed in Daniell's battery instead of the dilute acid, and in that case the zinc is not amalgamated; and in many experiments made by the author with Grove's battery, in which a saturated solution of the salt in question was employed in lieu of the dilute acid, the effect was certainly not diminished by the substitution; nay, in the few comparative experiments made on the subject, there appeared to be a considerable increase of power; for, with two batteries, of exactly the same size, one charged with dilute sulphuric acid, in contact with the amalgamated zinc,

and the other with the saturated solution of muriate of ammonia and unamalgamated zinc, the latter gave in eight minutes a volume of the mixed gases from the decomposition of water equal to that produced by the former in nine minutes and a half.

103. Various other modifications of Grove's battery have been proposed by different experimenters. A modification much used on the continent is called Bunsen's battery; it appears, however, to have originated with several individuals about the same time. The novelty in this battery is the substitution of carbon, or charcoal, for the platinum. The carbon is formed into a vessel, which is substituted in place of the porous vessel, and is filled with concentrated nitric acid. The carbon thus constitutes at once the porous cell for separating the liquids used, and the negative plate or element of the battery. The preparation of the carbon cylinders cannot be undertaken on a small scale; and, therefore, the process by which they are made need not be described.

104. M. de la Rive has substituted metallic oxides in place of the nitric acid in Grove's battery. The substitution had, however, been previously suggested by Mr. Grove himself. Either the peroxide of manganese, or the peroxide of lead, in a state of fine powder, may be used; the latter is most effective. The porous vessel is filled with the oxide, the platinum plate being in the middle of the vessel, and, consequently, closely surrounded by the oxide. After the vessel has been filled with the peroxide of lead, dilute sulphuric acid is introduced so as to fill up the interstices between the particles. It is hardly necessary to remark, that the peroxide suffers decomposition by the hydrogen evolved at the surface of the platinum. This battery possesses an intensity somewhat greater than that of Grove's.

105. The electro-metallurgist rarely requires a current more intense than that afforded by Daniell's battery; and where a greater intensity is necessary, two or three of Daniell's cells,

arranged as a series (64), are to be preferred to the batteries of Grove, Bunsen, and De la Rive.

106. The next modification of the battery we have to notice is the arrangement of Mr. Smee. In order to avoid the expense attendant on the removal of the hydrogen, by chemical means, in the batteries just described, Mr. Smee endeavours to effect the same object by mechanical means. Having observed, during the evolution of gaseous matter from different plates, that the bubbles of gas adhere very tenaciously to smooth surfaces, but are, on the contrary, quickly liberated from roughened ones, Mr. Smee precipitates the metal platinum in a finely divided state on the negative plate of his battery, so as to give it an infinity of points exceedingly favourable to the evolution of gas. The way in which this is effected will be understood by a perusal of the subsequent pages of this treatise. The battery of Mr. Smee differs only from those used long before the inventions of Daniell and Grove, in this preparation of the negative plate; and, like them, it is excited by dilute acid only.

107. It has been proposed to remove the hydrogen from the negative metal of the battery by using, instead of a metallic plate, a sheet of wire gauze, so inclined, that the hydrogen, instead of having to pass over the face of the plate opposed to the zinc, passes through the apertures to the surface of the liquid. The advantage to be gained by this substitution is very questionable. The hydrogen being removed from the plate, the latter is rendered more effectual; but as this removal is effected in the alteration in question, by the diminution of metal, the object is gained by directly making the sacrifice, to avoid which the alteration is proposed.

108. It is, indeed, doubtful if any of the plans proposed for the mechanical removal of the hydrogen are of much value, even when they accomplish all their inventors claim for them. The adhesion of hydrogen to the surface of the metal, renders



it, for the time being, inactive ; but the inactivity is attended by no direct loss, and it is only necessary to increase the size of the plates, in order to produce an instrument in which there is a sufficient extent of active surface, after deducting the inactive ; in other words, the only advantage that can be claimed for these batteries, is, that they produce a current of given power, in a somewhat less space ; but beyond economy in room (which in a battery is generally insignificant) there can be no pretence to superiority.

109. Amalgamated zinc and silver, roughened by sand-paper, or by immersion in nitric acid, form as good an arrangement as any at present known, excepting, perhaps, those having porous diaphragms.

110. In using a voltaic battery the first thing to be attended to, is the state of the zinc. If the amalgamation is perfect, there is not the slightest effervescence when the zinc is plunged into dilute sulphuric acid ; if there is any evolution of hydrogen from its surface, it must be amalgamated again. The plates of the acid battery may be immersed in a vessel containing one part of concentrated sulphuric acid to nine or ten parts of water ; and if, by bringing one end of a clean wire against the binding screw connected with the zinc, and the other end in contact with the screw of the copper or silver, a violent effervescence arises at the latter metal, the battery is in perfect order. In preparing Daniell's battery, the porous cell should be filled with the dilute acid, and the external copper vessel with a saturated solution of sulphate of copper, crystals of which salt, should be placed on the perforated shelf in the upper part of the copper cylinder—care being taken that the surfaces to be brought in contact, in making the necessary connections, are perfectly clean ;—the instrument may then be considered ready for use.

111. Instead of dilute acid, the internal or porous cell of Daniell's battery, may be filled with a saturated solution of sal ammoniac (hydro-chlorate of ammonia), or a solution of

common salt (chloride of sodium). In placing the crystals of sulphate of copper on the perforated shelf (91), care must be taken not to let any fall into the inner or porous cell. In such a case, metallic copper is precipitated on the zinc rod, and innumerable local circles (81) are formed, the injurious tendency of which, has been already pointed out. If any effervescence is observed to arise from the zinc rod, it should be removed, and the particles of copper, which, in such a case, will be generally found on it, carefully wiped off.

112. The reader must bear in mind that, in using a very dilute acid, a current, small in quantity, (and of an intensity dependent on the nature of the battery), will be generated; and that, by using a strong acid, a more copious current will be produced; he must also bear in mind that the strength of the acid employed does not in the least affect the intensity of the battery; a mixture of one part sulphuric acid, with a hundred parts of water, determines a current possessed of an intensity, equal to that produced by acid of the strength recommended, though the latter gives rise to a much more copious current. For example, suppose a battery of a given number of plates, and charged with an extremely dilute acid, have its electrodes introduced into water, and that it does not possess sufficient intensity to decompose that water, no augmentation of the strength of that acid will enable it to effect the decomposition. On the other hand, if the battery have power to decompose water, when charged with strong acid, the only effect produced by the most copious dilution, will be a diminution of the quantity of water decomposed; but if the same number of pairs be preserved, however dilute the acid be made, it will not lose its power to effect the decomposition.

113. The quantity of electricity generated in a battery may therefore be regulated in two ways—either by altering the strength of the acid, or by exposing a greater or less extent of surface to its action. A small battery, charged with a

strong acid, is the same in effect as a large one excited by weak acid, and *vice versâ*. The temperature of the apparatus has a very important influence on its action. If the battery is heated artificially, its action is much more rapid than under ordinary circumstances; while, in cold weather, it is much retarded.

114. It is important in using the common acid battery, consisting of plates of zinc, and copper or silver, to charge all the cells with acid of the same strength, and to fill each, with very nearly the same quantity; if either of these conditions be neglected, it will frequently happen, that the cells in which the acid is too dilute, or too small in quantity, become, not merely inactive, but a source of obstruction to the current generated in the other cells. When the whole of the acid in a cell is saturated, that cell becomes inactive; but as the current generated must pass through all the cells (65), it cannot pass through these inactive ones, without effecting decomposition of the sulphate of zinc, with which they are charged; the consequence is, the deposition of zinc where hydrogen was evolved, that is to say, on the copper or silver plate, and when the cell is next charged, the arrangement is inactive, owing to the presence of zinc on the copper or silver.

115. The removal of zinc accumulated on the negative plate of a battery, is easily effected. It is only necessary to immerse the copper or silver plate so coated into dilute acid, and place in contact with it, a silver or copper wire; or if there is the least portion of the silver or copper uncoated, that is sufficient to cause the removal of the zinc when the plate is immersed in acid. A voltaic combination is formed, by virtue of which (49) the zinc dissolves.

116. Before dismissing the subject of voltaic batteries, we would remark, that whatever form is given to an instrument of this kind, the amount of electricity generated by the consumption of a given amount of zinc is the same in each; they



differ only in the rapidity with which the development of the voltaic power takes place. In the invention of Daniell a flow of electricity of extreme uniformity is produced. We have a torrent of surprising intensity, but of transient duration, in the battery of Mr. Grove; and a copious flow of electricity, of moderate intensity, in the common acid battery, and that of Mr. Smee: but we repeat (for it cannot be too strongly urged upon the reader), that in all these instruments a like amount of this subtle agent is obtained by a like consumption of materials, the intensity alone being affected by the arrangements of Daniell and Grove. In Smee's battery this is not at all increased; the mechanical form of the surface of the negative plate only facilitates the escape of the hydrogen therefrom.

117. The experimenter is strongly recommended to use, in his early experiments, a Daniell's battery in preference to every other. He is much less likely to fail in his operations by its use; and, from the extreme regularity of its action, the character of the deposit is not likely to change, even during a long experiment.

118. A single cell of Daniell's battery possesses in general, sufficient intensity for electro-metallurgical processes. It will sometimes, however, be found advisable to use a series of two. In using the acid battery, one cell will be seldom found to have sufficient intensity; a series of two, three, or four, must sometimes be employed. The intensity requisite depends on the salt to be decomposed.

119. From what has been said of *quantity* and *intensity* in the voltaic battery, it will be understood, that by joining a number of battery cells together, in different ways, a quantity or intensity arrangement will be produced. If the plates or rods of zinc be joined together, and the copper or silver plates similarly connected, an arrangement will be produced, in which the *quantity* will be directly as the surface of the zinc, the intensity remaining the same as that of one cell. If, on the other hand, the zinc of one cell be joined to the

copper or silver of the next, and so on, through the series, a battery is formed, in which the *quantity* does not exceed that of one cell; but in which the *intensity*, is directly as the number of cells.

120. The electro-metallurgist may sometimes have occasion, in his experiments, to determine, accurately, the quantity or intensity of the voltaic current he employs; and a brief description of the instruments used for that purpose may be conveniently introduced here. These instruments depend for their action on the decomposing and magnetic powers of the electric current; the two commonly employed, are the voltameter and galvanometer.

121. The voltameter is a vessel in which water is decomposed by transmitting through it, a voltaic current; the oxygen and hydrogen evolved are collected either together or separately; and the volume of gas thus liberated, is an accurate measure of the quantity of electricity which has passed. This instrument is made of many different forms. *Fig. 11* represents one of the most convenient. It consists of

*Fig. 11.*



a glass vessel *a*, partly filled with dilute sulphuric acid; two platinum plates *b b* are connected with cups to hold mercury, or binding screws, *c c* on the base of the instrument. When the voltaic current is transmitted through the instrument by means of the mercury cups *c c*, decomposition takes place, and oxygen is evolved from one of the plates *b b*,

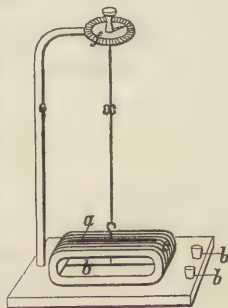
and hydrogen from the other. The gases are collected and measured by tubes suspended over the plates; or by closing the vessel *a*, and connecting a pipe with its top, the gases may be conducted to a pneumatic trough, and collected in a graduated jar.

122. The galvanometer is a magnetic needle stationed near,

and parallel with, a wire, conducting the current to be measured. A magnetic needle brought near a wire conducting a voltaic current suffers a deflection from its natural position (55); the extent and direction of this deflection are dependent on the amount of electricity passing, and the relative position of the needle and wire. A simple magnetic needle is a rude galvanoscope; but it affords no information as to the quantity of electricity passing. In order to render it a galvanometer, it is necessary to make the wire, intended to transmit the current, pass many times over and under the needle; the deflecting power of such a coil is directly proportionate to the number of its convolutions. In order to increase still more the sensitiveness of the galvanometer, it is usual to make it astatic; that is, to destroy, more or less, its directive power. This may be done by placing a magnet near the galvanometer; or it may be more conveniently effected by placing a second needle over the first; the north pole of the second being over the south pole of the first. Such an arrangement possesses little directive power, and is hence more sensitive to any deflecting force.

123. *Fig. 12* represents Ritchie's galvanometer; *a b* are the magnetic needles suspended in the coil *c*; the ends of this coil are connected with the mercury cups *d d* on the base of the instrument. The needles are suspended by a fine wire, or thread of glass, *x*, from the arm *e*. The wire, or thread of glass, is attached to a moveable index, which describes a circle on the graduated plate *f*. In order to use this instrument, the needles are allowed to assume their position in the magnetic meridian, and the coil *c* (which is moveable), is brought in the same plane; on passing a current from a battery through the coil, the needles are de-

*Fig. 12.*





flected. The index, or hand, is now turned in a direction opposite to that in which the needles have been deflected, until they are brought into the same plane as that in which the coil is situated. The number of degrees through which the index has been turned, as indicated on the graduated circle  $f$ , indicate the quantity of the current by which the deflection is produced. The indications of this instrument are comparative; the quantities of electricity passing in any two experiments being to each other, as the angles through which the wire  $x$  must be twisted, to restore the position of the needles. .

124. The galvanometer measures a current having the feeblest intensity; while the voltameter completely intercepts, and, consequently, does not measure, a current which does not possess sufficient intensity to decompose water. For accuracy, the voltameter is superior to the galvanometer.

125. In using a voltameter in the voltaic circuit, it must be recollected that the force, or intensity, of the current is diminished by the amount necessary to effect the decomposition of water. The obstruction, which is occasioned by the introduction of a galvanometer in the circuit, is so small (owing to the course of the current being through a metallic conductor), that it may be neglected, excepting in experiments of extreme delicacy. The electro-metallurgist has rarely occasion to use either the voltameter or the galvanometer.

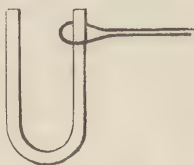
## CHAP. IV.

## ON MAGNETO-ELECTRICITY AND THE MAGNETO-ELECTRIC MACHINE.

126. THE identity of electricity and magnetism was suspected by the early electricians, and many experiments were instituted, in the hope of obtaining electrical indications from the magnet. The proof of their identity, and the use of the magnet as a source of electric power, have, however, been reserved for modern times. The admirable researches of Faraday have supplied nearly all the evidence and information we have on this subject.

127. If a loop of wire, the ends of which are connected with a galvanometer (123), be made to approach and encircle one end, or pole, of a powerful magnet, the galvanometer needle is powerfully deflected, demonstrating the passage through the wire of an electric current. Immediately the wire becomes stationary, the galvanometer needle ceases to be affected; and, on withdrawing the wire, the needle is deflected in the opposite direction, indicating an opposite electric current. This experiment is represented in *fig. 13*.

Fig. 13.



128. If, instead of a single loop, the wire is coiled into a helical or corkscrew form, and this helix be brought on the arm of the magnet, the needle is more powerfully deflected; the electric current generated being proportionate to the number of coils in the helix.

129. It will also be observed that the action is more powerful, as the motion of the wire is quicker.

130. Instead of making the magnet and wire approach each other, a bar of annealed or soft iron may remain permanently in the helix ; and a magnet, alternately touched against and detached from, the bar of iron, determines the production of the currents in question.

131. By coiling a long wire many times round a core of soft iron, so as to form a compact helix, in which the several coils are insulated from each other, by covering the wire with cotton, or some non-conductor of electricity, and by placing the north pole of a powerful magnet in contact with one end, and the south pole of another in contact with the other end, an arrangement is formed, from which, by suddenly detaching the magnets with a blow, very powerful currents may be obtained. If the ends of the wire coil are dipped into a cup of mercury, and one of them removed at the moment of detaching the magnets, the electric current generated passes between the surface of the metal and the retiring wire in the form of a spark. In short, this magneto-electric current exhibits all the phenomena of the voltaic current. In passing it through water, that compound is decomposed ; it also gives powerful shocks, and deflagrates metals.

132. In order to develop these magneto-electric currents with rapidity and effect, the necessary motion is communicated to the magnet, or coil of wire, by machinery. Various arrangements have been proposed for this purpose, the most convenient of which is that of Mr. Saxton.

133. Saxton's magneto-electric machine may be briefly described as a powerful compound horse-shoe magnet, supported horizontally, and in front of which an armature of soft iron, on which a long copper wire is coiled, rotates on an axis situated midway between the arms or poles of the magnets. The rotating armature consists of a bar of soft iron bent twice at right angles. When this armature is in a



horizontal position, its arms are in the same plane as, and are opposite to, the poles of the magnet, but as it rotates, they assume a vertical position, and thus alternately approach and recede from, the magnetic poles. As the ends of the armature approach the magnetic poles, a powerful magnetism is induced in them, which arrives at a maximum when they are opposite to the magnetic poles; as they recede from the magnet, they become demagnetised; and when they are at right angles to the magnetic poles, that is to say, in a vertical plane, they are not at all magnetic. Hence, at every semi-revolution, the armature becomes highly magnetic, and is again demagnetised. The consequence of the induction of magnetism in the armature, is the determination of a powerful magnetic current in the wire surrounding it, and by an elegant mechanical arrangement, this current is collected, and may be made to exhibit all the phenomena of an electric current from any other source.

134. From what has been already said (127), it will be evident that two currents will be generated during every revolution of the armature, namely, one as the armature approaches, and another as it leaves, the magnet; these currents are in opposite directions, and if not insulated from each other, their effects would be completely neutralized. The difficulty of directing these currents in the same direction, combined with the small quantity of electricity, which it was supposed could be obtained by magnetic influence, caused the application of the magneto-electric machine to the art of electro-metallurgy to be long neglected.

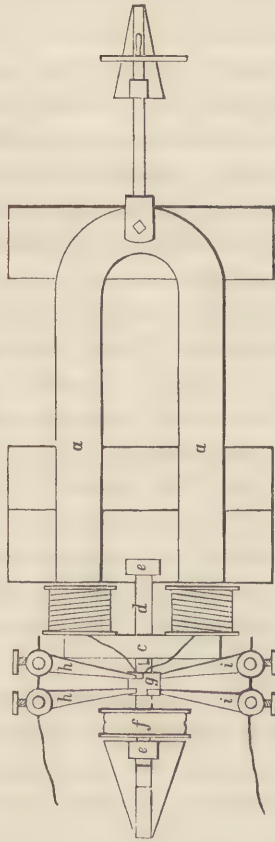
135. Mr. Sturgeon appears to be the first who deposited metals by this apparatus, but his experiments were on a small scale; and it is to Mr. J. S. Woolrich, of Birmingham, that the art is indebted for the perfection of the magneto-electric apparatus, and the development of its extraordinary power as an electro-metallurgical instrument.

136. Mr. Woolrich constructs machines after two models;

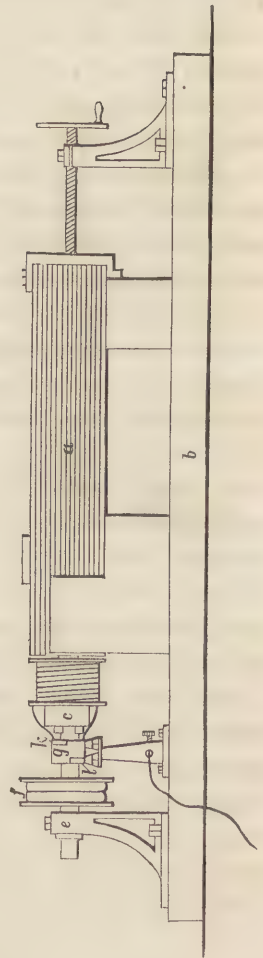
one resembles, to a considerable extent, that of Mr. Saxton, and is used where a moderate amount of work is to be performed, and the other is a modification of one of the early magneto-electric machines; this latter form is employed where large quantities of electric power are required.

137. The small magneto-electric machine is represented in plan in *fig. 14*, and in elevation in *fig. 15*. *a* is a powerful

*Fig. 14.*



*Fig. 15.*



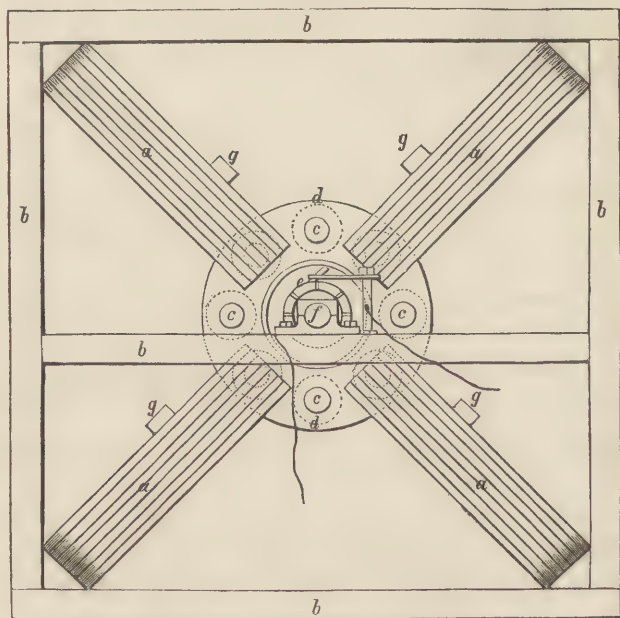
horse-shoe magnet, composed of any convenient number of magnetic bars fastened together; this magnet is supported horizontally on the table *b*; *c* is the armature affixed to the end of the spindle or axis *d*; this axis works in bearings at *e e*, and is made to rotate by means of a band and the pulley *f*; a contrivance for determining a uniform direction in the currents (134) is attached to the axis near the pulley *f*; it is called the break or divider, and is composed of the following parts:—*g* is a cylindrical piece of wood fixed on the axis; two semi-circular bars of metal *k l* (brass) are fitted on this cylinder of wood; these pieces of metal are carefully insulated from each other by the insertion between their ends of two small pieces of wood; *h* is a spring supported on the base of the instrument by a pillar; this spring presses on the upper part of the cylinder *g*, and a similar spring *i* presses on the under side of the cylinder; one end of each coil is attached to one of the semi-circular pieces, and the other end of each coil to the other semi-circular piece. The similar end of each coil must be joined to the same semi-circle of metal; that is to say, those ends must be joined which, supposing the armature to be a straight bar of iron, and the wire on each end to be coiled in the direction of the motion of a watch-hand, or of a screw on being driven home, constitute the beginnings, and similarly those constituting the endings, of the coils. The semi-circles *k l* represent the terminations of the coils; and the springs *h i* pressing on them are in electrical communication therewith. Now, it will be observed, that by the rotation of the armature and break, the springs *h i* are alternately in connection with the beginnings and endings of the coils. When the armature is vertical, there is no magnetism in it, and, consequently, no current in the coil of wire; and at that moment the springs *h i* press on the pieces of wood which separate the semi-circles *k l*. As the armature quits its vertical position, and approaches the magnetic arms, it becomes powerfully magnetic, and a current



is determined through the coils. The springs *h i* now press on the semi-circles *k l*, and receive from them the current. As the armature, by a half revolution, becomes again vertical, it leaves the poles by which it was magnetised, becomes neutral, and again approaches the poles in an opposite direction; that is to say, that end of the armature which was last opposed to, and is now leaving, a north pole, is approaching a south pole, and *vice versâ*; but at the same moment each of the springs *h i* quits the semi-circle against which it presses, and comes in contact with the other; hence, by reversing the connection at the moment the direction of the current is changed, the springs *h i* are always in the same relation to the currents produced. By rapidly rotating the armature, and connecting a wire with the pillars carrying the springs *h i*, a constant current of electricity passes through the wire.

138. The large magneto-electrical machine is represented in *fig. 16*. It consists of four, six, or eight compound magnets,

*Fig 16.*



arranged as radii to a common centre. A drum, or wheel, rotates rapidly between the arms of these magnets; and, carrying the armatures on its periphery, conveys them rapidly during its rotation between the arms of each magnet, so as to induce in them a momentary magnetism. There are thus four, six, or eight armatures (as the case may be) generating powerful currents at the same time; and the combined effects of these currents is proportionately great:—*a a* are the magnets supported on the frame *b*; *c c* are the armatures fixed in the periphery of the wheel or drum *d*; the break or divider is shown at *e*; the rotation of the drum *d* is effected through a pulley on the axis *f*.

139. The intensity of the current of a magneto-electric machine depends on the length and diameter of the wire of which the coils on the armature are made. If the wire is long and of small diameter, the current is of great intensity, and small in quantity. (58.) If, on the contrary, a short thick wire is used, the current is large in quantity, and of small intensity.

140. The intensity of the current is altogether dependent on the length of the coil, but the quantity may be affected by other circumstances. The power of the magnet, and the rapidity with which the armature revolves, are circumstances which determine a difference in the quantity of the current generated. As the power of the magnet is diminished, the quantity of the current diminishes; as it also does, in proportion as the rapidity of the revolution of the armature decreases.

141. Experiments are yet wanting, to determine accurately the relation which exists between the length and diameter of the wire, and the intensity and quantity of the induced current; it appears, however, probable, from limited experiments, that in using wires of different lengths and diameters (all other circumstances remaining the same), the quantity increases and diminishes inversely as the intensity; that is to

say, by using a wire of a given length and diameter, a current is obtained of a certain quantity and intensity, and by whatever alteration in the length and diameter of the wire, we effect a change in either property, the other is increased or diminished in the inverse ratio.

142. The direction of the current is not dependent on the direction of the rotation of the armature.

143. The absolute size of the magneto-electric machine may be varied to suit the purpose to which it is intended to be applied; there are, however, proportions between the various parts, which must be observed, in order to obtain the maximum effect. All that is said in this treatise relative to the proportions of the magneto-electric machine, has reference only to its use as an electro-metallurgical instrument.

144. The small machine from which *figs.* 14 and 15 were made, consists of ten magnets, 27 inches long; they are made of steel  $2\frac{1}{4}$ -in. broad, and  $\frac{3}{8}$ -in. thick. The distance from centre to centre of the arms is 5 inches. The armature is made of soft iron  $1\frac{7}{8}$ -in. diameter, and the wire of which the coils are made, is  $\frac{1}{8}$ -in. diameter, and each coil 90 feet long. In making 1000 revolutions per minute, this machine deposits 120 ounces of silver per week from the sulphite solution described in another part of this work.

145. The large machine represented in *fig.* 16 consists of four compound magnets, 2-ft. 3-in. long; each magnet is composed of ten bars. These bars are made of steel  $2\frac{1}{4}$ -in. broad, and  $\frac{3}{8}$ -in. thick. The drum or wheel carrying the armatures is 2 feet in diameter. The distance between the poles of the magnets is 6 inches. The armatures are cylinders of iron  $2\frac{1}{2}$ -in. diameter and 6-in. long. Each armature is covered with a coil of wire  $\frac{1}{8}$ -in. diameter and 90 feet long. When the drum or wheel carrying the armatures makes 650 revolutions per minute, this machine deposits from 300 to 400 ounces of silver per week from the sulphite solution.



146. The following remarks, relative to the magneto-electric machine, are of a practical nature. The iron, of which the armatures are made, should be as pure and as well annealed as possible, in order that the magnetic induction may take place in it with rapidity and intensity.

147. The copper wire surrounding the armatures should be well annealed, and closely covered with cotton; it is also desirable to coat each layer or stratum of wire with a resinous cement, in order to insulate it perfectly from the other layers; a cement composed of equal quantities of bees' wax and resin answers very well.

148. The quantity of electricity generated by the magneto-electric machine may be adjusted to the work to be done with the greatest nicety. This adjustment may be effected in two ways;—either by diminishing the rapidity of the rotation of the armature (140), or by diminishing the intensity of the magnetic induction. The latter is the simplest and most manageable.

149. In order to diminish the current in the small machine (*fig.* 14 & 15), the magnet is made to slide horizontally by means of a screw, and it can thereby be placed at any distance from the rotating armature. In the large machine (*fig.* 16) the same effect may be produced by using keepers, or bars of iron, laid across each magnet; by sliding these keepers near the poles of the magnet, the magnetic circle is completed, partly through them, and partly through the rotating armatures. When the full power of the magnets is required, the keepers must be wholly removed; when they are used, they should be fixed in their places by pins or cotters, so that accident may not occasion any change in their position.

150. The magnets of these machines (contrary to what would have been expected) do not appear to lose their power during the most prolonged action to which they have been subjected.

151. The first cost of the magneto-electric machine is certainly greater than that of the voltaic apparatus necessary to produce the same amount of power ; but the current or working expense is incomparably less, being limited to a trifling motive power ; and the economy of the magnetic machine must eventually gain for it a preference to the voltaic battery, where metal is to be deposited on a business scale. The wear and tear of these machines is, of course, limited to the friction between the axis and its bearings, and that between the break and springs.

152. The magneto-electric machine appears destined to supersede every other apparatus in the deposition of metals of low equivalent proportions (35), as the expense of the voltaic battery in such precipitations, renders the process an expensive one. Thus, in depositing zinc, as in zincing iron, supposing two cells, arranged as an intensity battery, to be employed, the quantity of zinc deposited would be just one-half of that, consumed in the battery, and very nearly the same proportion would obtain in the case of copper. Hence, the expense of depositing, compared with the value of the metal deposited, is very great ; in the magnetic machine, on the contrary, the expense of depositing is limited to the power required to produce the rotation of the armatures.

153. The uniformity of the current developed in the magneto-electric machine is not the least of the many advantages this machine possesses. In the best constant battery the quantity varies during the course of several hours ; and even the best operators with the battery find it necessary to give close attention to the state of the instrument and the progress of the deposition. With the magnetic machine the deposition goes on with extreme regularity ; and, when once adjusted, may be left for any length of time without fear of derangement. So accurately is the deposition by this machine proportioned to the time of working, that, in an establishment in

Birmingham where this process is extensively employed, the quantity of metal deposited is estimated by the time during which the machine works; repeated weighings having demonstrated, that the relation between the time of working and quantity of deposited metal, is sufficiently accurate.\*

\* The process of magneto-plating is extensively carried on by Mr. Prime, of Northwood-street, Birmingham, by whose kindness the author has been enabled to verify many of the statements contained in this chapter.

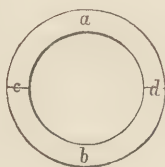


## CHAP. V.

ON THE PRODUCTION OF ELECTRICITY BY HEAT  
AND THERMO-ELECTRIC BATTERIES.

154. If a circuit be formed of two metals, and heat be applied at one of the points of junction, an electric current will be determined through the arrangement; or if, instead of applying heat, one of the junctions be cooled, the same effect will be produced; it being only necessary to produce, either by heating or cooling one of the junctions, a difference of temperature in them.

155. The accompanying figure (*fig. 17*), represents a simple thermo-electric arrangement.



*Fig. 17.* *a* is a semi-circular bar of bismuth, and *b* a similar bar of antimony. These bars are joined together, by soldering, at the points *c d*. By applying heat to one of the joinings, *c d*, an electric current will circulate through the whole arrangement, which current will be increased by cooling the other joining, so as to produce a greater inequality of temperature. A magnetic needle brought near such an arrangement, will be deflected (122); and if the circuit be interrupted at some point, and be connected by a saline solution, easy of decomposition (58), the solution will be resolved into its constituent elements. These and other phenomena, demonstrate the circulation of an electric current.

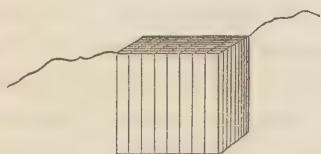
156. Different combinations of metals, possess the power of

determining thermo-electric currents, in different degrees. The most effective combination is that of bismuth and antimony ; but, owing to the brittleness of these metals, other combinations are used,—as of platinum and iron, German silver (an alloy of nickel) and iron, or copper.

157. The thermo-electric current is, however, possessed of a very feeble intensity, and on that account, has not hitherto been applied with success to the deposition of metals.

158. Attempts have been made to increase the effects of the thermo-electric current by combining together a number of pairs, so as to form a thermo-electric battery, as voltaic pairs are combined together to form a voltaic battery. *Fig. 18*

*Fig. 18.*



represents a thermo-electric battery. It consists of a number of bars of iron, and others of German silver, soldered together end to end, so as to have regular alter-

nations of the two metals. The bars are piled side by side, but separated from each other by some non-metallic substance. The whole forms a compact mass, which, when in use, is heated at one end, and cooled at the other. By the application of heat to the lower end, the first, third, fifth, &c., joinings are heated ; while, by the application of water to the upper end, the second, fourth, sixth, &c., joinings, are kept cool.

159. The intensity of a thermo-electric current does not increase as that of the voltaic battery does, in proportion to the number of elements, or pairs, in the battery ; nor is it at all clear, that there is any analogy between the constitution of the voltaic, and thermo-electric batteries. It has been shown (65) that the electric current in the battery, in passing through the different cells, must effect a decomposition in each ; and that, if decomposition be prevented in one cell, the whole must become inactive, as the passage of the current

is dependent on the decomposition. Now, in passing through the various cells, the current is not only not opposed, but there is, as it were, a disposition to decomposition, which is favourable to the passage of the current, and by which the current acquires intensity.

160. The constitution of the thermo-electric, however, does not at all resemble that of the voltaic battery. A bar, or wire of metal, can transmit a hundred currents from as many batteries, without those currents interfering with each other; and so in the thermo-electric battery, if only *one* junction be heated, a current is generated which can circulate freely through all the other pairs, without impediment. On heating a second or third alternate junction, a second and third current will be produced, which will circulate through the whole arrangement, independently of the current produced at the first joining; and so the current of a battery of this kind will be, in quantity, the sum of the individual currents, while the intensity will be wholly unaffected by the number of alternations, and dependent only on the nature of the metals associated.

161. It has been many times announced that thermo-electric batteries have been constructed which effect *directly*\* the decomposition of water. Experience has not confirmed these reports; and there is also reason to doubt the correctness of those statements, in which the successful reduction of metals, by thermo-electricity, is represented to have been accomplished.

\* By induction, currents of the feeblest intensity can be made to develop others of great intensity; and in this way the intensity of a thermo-electric current may be increased, so as to give sparks, shocks, &c., and effect decompositions; but such induced currents are so inferior to those obtained with the voltaic battery, that, for practical purposes, they are worthless.



## CHAP. VI.

ON THE SALTS FROM WHICH METALS MAY BE  
PRECIPITATED.

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162. METALS may be precipitated by voltaic agency from any of their soluble salts (38), or from solutions of those of their salts, which are insoluble in water, in any menstruum capable of dissolving them. The reduction, by voltaic agency, of some of the metals is effected with extreme facility; while the reduction of others is accompanied with many difficulties. The precipitation of gold, silver, copper, &c., in the reguline state, is easily accomplished; while the reduction of potassium, sodium, manganese, &c., is attended with difficulty.

163. The reduction of the same metal from its different salts is attended with different degrees of difficulty; thus, the reduction of copper from the nitrate and sulphate of copper takes place under the influence of a feeble voltaic current, while the precipitation of the same metal from its acetate, requires a current of considerable intensity (58).

164. The metals which are reduced by voltaic agency for the purposes of art are few in number; and it is only to those metals that particular attention will be given:—they are gold, silver, platinum, copper, and zinc. The other metals, which may be conveniently deposited by electric agency, will afterwards be briefly studied.

165. The precipitation of the noble metals received early attention at the hands of those who experimented with the

electrotype; but the successful application of the voltaic battery in their reduction, is of but recent date. Mr. Spencer relates experiments he made with gold, and describes a plan of effecting its reduction, which, (though the materials are in connection with the voltaic battery,) is wholly unconnected with electric agency. The plan alluded to consists in forming an arrangement similar to that called the single cell apparatus described in the following chapter. The porous cell is charged as usual, and the outer vessel filled with a very dilute solution of the chloride of gold, to which a few crystals of carbonate soda have been added. If a battery and decomposing cell be used, Mr. S. recommends that the former be charged with cold water only. A film of gold is deposited on the surface thus treated, but it is extremely thin; and, however long the connection with the battery is maintained, it cannot be made thicker—a sufficient proof that the cause of the deposition does not exist in the battery; indeed, the effect is produced without the battery, and, therefore, cannot with any propriety be called a voltaic precipitation. A mode of precipitating gold has been described in the “*Annales de Chimie*,” by M. de la Rive. It is essentially the same as that of Mr. Spencer. The process is described at great length by M. de la Rive, but, as it is so inferior to the methods at present adopted, it is useless to describe it. Subsequent experiments have supplied us with processes, by which works of art may be multiplied in gold and silver, with as much ease as in copper.

166. Gold may be precipitated from its chloride, bromide, iodide, cyanide, sulphite, and hypo-sulphite.

167. Chloride of gold is formed by dissolving gold in nitro-muriatic acid—a mixture also called *aqua regia*, from its property of dissolving this metal. *Aqua regia* is formed by adding together one measure of nitric acid and two measures of hydro-chloric or muriatic acid. To procure chloride of gold, the metal is added to about four times its weight of *aqua regia*, and a gentle heat applied. Decomposition of

the two acids takes place; the hydrogen of the hydro-chloric acid combines with the oxygen of the nitric acid, forming water; while the other elements of the decomposed acids are liberated; the nitric oxide of the nitric acid escapes, and the chlorine of the hydro-chloric acid remains in solution, and is the real solvent of gold.

168. When the metal is dissolved, the solution should be carefully evaporated. It is necessary to stop the evaporation when the solution becomes of a dark red colour and emits chlorine, which is readily detected by its odour. On setting the solution aside, the chloride forms a dark red crystalline mass. The salt thus formed is the per-chloride or sesquichloride of gold, and consists of two equivalents (35) of gold, and three equivalents of chlorine. If the evaporation of the solution be carried too far, a portion of chloride of gold (properly so called) will be formed. This compound consists of two equivalents (35) of gold, and one equivalent of chlorine; it is insoluble in water, but when in contact with that liquid suffers decomposition; it resolves itself into the per-chloride and metallic gold, the former dissolves and the latter remains undissolved. The operator may, therefore, conclude, that when any metallic gold appears in the solution of the chloride, the evaporation for the production of the crystalline mass has been carried too far. This salt is the first from which gold was successfully precipitated; but it has now fallen into disuse, owing to its inferiority to many of the solutions more recently proposed.

169. Bromide of gold may be formed by the direct union of bromine with gold. Bromine is an elementary body (31), existing, at ordinary temperatures, in the form of a dense liquid, of a very dark red colour; it is very volatile, and, at common temperatures, gives off dense red fumes, having a pungent, suffocating odour. In order to form the bromide of gold, the metal, in a state of fine division, should be digested in bromine. The application of a gentle heat favours the forma-

tion of the compound, but, owing to the volatility of bromine, it must be cautiously applied. The digestion should take place in a well closed vessel, a stoppered glass bottle, for example. In order to prevent the evaporation of bromine, it is usual to pour a small quantity of water into bottles containing that substance. Water is not miscible with bromine; and, being much lighter, floats on the surface, and forms a stratum, through which the bromine evaporates with difficulty. Bromine is slightly soluble in water, and the stratum of that liquid speedily acquires a beautiful red colour by dissolving a portion of it. A considerable quantity of bromine evaporates from this aqueous solution, which, becoming weaker, replenishes itself by dissolving more bromine, and thus, even when the precaution is taken of covering the bromine with water, evaporation goes on with considerable rapidity; it is hence advisable to keep the mixture of bromine and gold in a stoppered bottle, even when covered with a stratum of water.

170. In order to procure gold in that state of fine division which is favourable to its solution in bromine and other solvents, the metal should be dissolved in *aqua regia* (167), and proto-sulphate of iron (green copperas) added to the solution. The gold is precipitated as a brown powder, which has no resemblance to gold, but which, nevertheless, is that metal in a state of purity, and of minute division. This powder is readily taken up by all the solvents of gold.

171. The bromide of gold is a salt of a rich red colour, and from its aqueous solution, the metal may be precipitated by voltaic agency. In its chemical relations it closely resembles the chloride of gold. It is more expensive in its preparation than the chloride, and possesses no equivalent advantage; indeed it is inferior, for electro-matallurgical purposes, to many of the other salts of gold. Its use was first proposed by Mr. Spencer; it is, however, rarely, if ever, employed for manufacturing purposes.



172. Iodide of gold may be formed by digesting hydriodic acid, with oxide of gold ; it may also be prepared by adding a solution of iodide of potassium to a solution of chloride of gold (167). Iodide of gold is of a yellow colour ; it is insoluble in cold water, and but slightly soluble in boiling water. It is dissolved readily by a solution of iodide of potassium, and from its solution in that menstruum, gold may be precipitated by the voltaic battery. Its use was first proposed by Mr. Spencer, but it possesses no advantages, and has hence never been generally used.

173. Oxide of gold may be made by adding a cold solution of potash to a solution of chloride of gold (167). The potash must be added cautiously, as an excess redissolves a portion of the precipitated oxide. It may also be obtained by adding magnesia to the solution of the chloride ; and the latter method is to be preferred. The precipitated oxide should be washed first with pure water acidulated with nitric acid, and afterwards with pure water alone.

174. Cyanide of gold may be formed by adding metallic gold, in a state of fine division (170), to a solution of cyanide of potassium. The metal dissolves slowly in the solution, but the action may be quickened by the application of heat. It may, however, be more readily prepared, by the addition of oxide of gold (173) to the solution of cyanide of potassium, or any of the salts of gold may be substituted for the oxide, but the latter is recommended. The solution may be favoured by boiling the liquid. A solution much used for electro-metallurgical purposes, is formed by adding two pounds of cyanide of potassium to one gallon of water, and saturating the solution with oxide of gold.

175. Cyanide of potassium may be made in various ways. It may be formed by the direct union of its elements. If potassium be heated in cyanogen, it burns with a beautiful flame ; cyanogen is absorbed, and the cyanide of potassium formed. This process cannot be used for its production in

large quantities. One of the simplest and most economical modes of forming it, is to heat the salt known by the names of prussiate of potash, ferro-prussiate of potash, and ferro-cyanide of potassium. It is known in commerce as prussiate of potash. It should be put in a close vessel, and heated to redness, and, after cooling, the addition of water will dissolve away the cyanide of potassium, which may be obtained in crystals by evaporation. The latter, however, is not necessary, as it must be used in the state of solution. The salt thus procured is not quite pure, as a portion of the prussiate generally escapes decomposition; the impurity is, however, of little consequence, and the salt thus obtained answers every purpose. In order to obtain the cyanide free from impurity, it should be dissolved in alcohol; the cyanide is largely soluble in that menstruum, and is dissolved, while the prussiate is insoluble, and remains at the bottom of the vessel. By decanting the clear solution, and evaporating or distilling off the alcohol, the cyanide of potassium may be obtained, in the form of a white crystalline mass, perfectly free from the prussiate.

176. Prussiate of potash may be considered as a compound of two equivalents of cyanide of potassium, with one equivalent of proto-cyanide of iron\*; the former undergoes no change on exposure to a red heat, while the latter is decomposed into carburet of iron, with evolution of nitrogen gas. The carburet of iron forms a spongy mass, which absorbs the fused cyanide of potassium, and from which it is afterwards separated by water or alcohol.

177. By the process just described (175), a loss of one-third of the cyanide contained in the prussiate is sustained;

\* Chemists are by no means agreed respecting the proximate constitution of the class of salts described in this chapter as cyanides. It is, however, certain that they are not simple cyanides; but being commonly called so, it has been thought better to retain their common names in the present work, than to introduce others which involve theoretical considerations.

but a modification of the process has been pointed out by Liebig, by which this loss is avoided. It is as follows:—eight parts of the prussiate are dried on a hot plate of iron, then finely powdered, and mixed well with three parts of dry carbonate of potash, and thrown at once into a Hessian crucible, previously heated to redness, and kept at that temperature; the mixture fuses into a brown mass, with a lively evolution of gas. After a few minutes, when the fluid mass has become red-hot, its dark colour is seen to become brighter, and on continued fusion, the salt becomes clear and of an amber yellow tint. If, from time to time, a hot glass rod be immersed in it, the adhering mass, on cooling, is at first brown, afterwards yellow, and at last, towards the close of the operation, clear and colourless as water, and solidifies into a shining white crystalline mass. During the fusion, brown flocks are seen floating in the fluid mixture, which, subsequently, unite into a spongy mass, and assume a light grey colour. If the crucible be now removed from the fire, and allowed to cool somewhat, the grey powder generally settles entirely at the bottom; this is facilitated by stirring once or twice with the glass rod. The fused mass may now be easily poured into a warm porcelain dish, without a particle of the sediment accompanying it. This mass consists of two combinations, of which the cyanide of potassium forms the chief portion; the other compound is the cyanate of potash, in the proportion of five of the former to one of the latter. The reaction in the fusion of the yellow prussiate with carbonate of potash, is as follows:—at the commencement, the proto-cyanide of iron of the ferro-cyanide is decomposed, and forms cyanide of potassium with the potash of the alkaline carbonate, and the proto-carbonate of iron, which is deprived of all its oxygen, at a higher temperature, by the cyanide of potassium. In consequence of this reduction, cyanate of potash and pure metallic iron are obtained. From two equivalents of the ferro-cyanide of potassium we thus obtain five equiva-

lents of the cyanide, that is, one-fourth more than by fusing it alone. The cyanate of potash mixed with it has no injurious influence in any one of its applications. The presence of cyanate is readily detected, by the effervescence caused from the escape of carbonic acid, on the addition of an excess of acid, and an ammoniacal salt is afterwards found in the liquid. The explanation given above of the formation of the cyanide of potassium under the conditions described, is not absolutely correct, as the proto-carbonate of iron, previous to its reduction, is decomposed into carbonic acid, carbonic oxide, and the black oxide of iron, at the expense of which an undeterminable quantity of cyanate is formed, more than the formula indicates. The metallic iron is precipitated, and the sides of the crucible are covered by cyanide of potassium, to obtain which, it is only necessary to remove with cold water all that is soluble, and to warm the solution with some sulphuret of iron, which easily dissolves in it. The cyanide of potassium is thus obtained, on evaporation again, in the form of ferrocyanide, and sulphuret of potassium remains in the mother-ley.

178. Gold may be precipitated with great facility, from the solution of its oxide in sulphite of potassa. The use of this salt for electro-metallurgical purposes, was first proposed by Mr. J. S. Woolrich. In order to form this solution, oxide of gold precipitated with magnesia (173) is added to a solution of sulphite of potassa, until the latter is saturated. After saturation, one-fifth part more of the solution of sulphite of potassa must be added to the solution of gold, as it is necessary to the proper working of the solution, that the sulphite of potassa be in excess.

179. The solution of sulphite of potassa is made as follows:—28 parts of pearlash of commerce are dissolved in 30 parts of water, by boiling in an iron vessel. The solution is filtered when cold, and diluted with 14 parts of water. Sulphurous acid gas is passed through the solution, until it is saturated. The liquor is again filtered, and is then fit for use.



The process for making this solvent is a simple one ; the only precaution to be observed is, not to add the sulphurous acid in excess.

180. Sulphurous acid gas, for making sulphite of potassa, may be made as follows :—Concentrated sulphuric acid (oil of vitriol) is poured into a retort, or flask, and filings or turnings of zinc, iron, or copper added thereto ; or mercury may be used instead. Heat is carefully applied to the flask, or retort, and regulated so as to cause the evolution of gas with the desired rapidity. Decomposition of the sulphuric acid is effected, the metals combine with a portion of its oxygen, and sulphurous acid gas is liberated. The gas is conducted into the alkaline solution, contained in Wolf's, or three-necked, bottles, until the solution absorbs no more.

181. Gold may be precipitated from the solution of its hypo-sulphite. This solution may be readily made by adding chloride of gold to a solution of hypo-sulphite of soda or potassa. It is, however, inferior to the cyanide and sulphite for electro-metallurgical purposes. Hypo-sulphite of soda may be made in the following manner :—Sulphurous acid gas (180) must be passed through a solution of soda until it absorbs no more. A solution of sulphite of soda is thus formed :—a quantity of flowers of sulphur is introduced into the solution of sulphite, and allowed to remain there twenty-four hours ; the solution dissolves a little sulphur, and becomes a solution of hypo-sulphite of soda. It must be separated from the flowers of sulphur by filtration or decantation ; and carefully evaporated at a temperature below the boiling point. Crystals of hypo-sulphite will form as the solution cools. It is not, however, necessary to crystallize the salt, as a solution of hypo-sulphite of soda, made from a solution of the sulphite, of the strength recommended (179), answers very well.

182. A new method of making hypo-sulphite of soda has recently been proposed, by which the salt may be formed

much more economically. Carbonate of soda is carefully dried, by exposure to heat, and when perfectly deprived of water, is reduced to a fine powder. This powder is intimately mixed with not less than one-fifth its weight of sulphur; an excess of sulphur is not prejudicial. The mixture is gently heated in a porcelain vessel on a sand-bath, and is constantly stirred during its exposure to heat. The mixture assumes a dark colour, and eventually becomes almost black. The change of colour indicates the decomposition of the carbonate of soda, and formation of sulphuret of sodium. The mixture must now be carefully stirred, as much of the success of the process depends on the proper exposure of the sulphuret to the air. The colour again becomes lighter, and eventually the dark-brown pasty mass is converted into a whitish powder, which is principally sulphite of soda. After cooling, water must be added to take up the sulphite formed, and the solution filtered. Flowers of sulphur must now be added to the solution, and allowed to digest twenty-four hours. The solution should again be filtered, to separate the flowers of sulphur, and cautiously evaporated at a temperature below the boiling point. On setting the solution aside, crystals of hypo-sulphite of soda will be deposited. This process, if properly conducted, succeeds well, and nearly the whole of the carbonate becomes converted into hypo-sulphite. It is however, only by extreme care that so successful a result can be obtained; and usually a considerable quantity of carbonate of soda will be found in the solution, from which, however, it may be separated by crystallization. If the mixture of the carbonate and sulphur be heated too quickly, or the temperature be raised too high, a portion of the sulphur takes fire, and burns away; and, unless there be an excess, an equivalent portion of the carbonate of soda escapes decomposition. It is also necessary to expose the sulphuret to long continued heat, and stir it well, otherwise the whole of the sulphuret is not converted into sulphite.

183. Gold may be deposited, by voltaic agency, from many solutions besides those enumerated. A solution of sulpho-cyanide of gold in sulpho-cyanide of potassium may be used for this purpose, as well as a solution of oxide of gold in chloride of potassium, or chloride of sodium; but as these solutions are inferior to those already enumerated, the mode of preparing them need not be given. The solutions of cyanide and sulphite of gold are superior to all others for the use of the electro-metallurgist.

184. Silver may be most conveniently precipitated from its cyanide, sulphite, hypo-sulphite, sulphate, acetate; and the solution of most of its salts, in ammonia.

185. Cyanide of silver may be made by adding oxide of silver to a solution of cyanide of potassium. A solution composed of three pounds of cyanide of potassium dissolved in two gallons of water, and saturated with oxide of silver, answers well for electro-metallurgical depositions. The true nature of the salt thus formed is not well understood; by some it is regarded as a solution of cyanide of silver in cyanide of potassium, while by others it is regarded as a salt analagous in constitution to the ferro-cyanide of potassium, and, according to which view it is called the argento-cyanide of potassium. The same remarks apply to the analagous salts of gold, copper, &c. The cyanide of silver is an excellent salt from which to precipitate silver; it is equalled only by the sulphite; and, but for the spontaneous decomposition which it slowly undergoes, would be superior to every other.

186. Oxide of silver (185) may be prepared by the addition of lime water, or a solution of caustic potash to a solution of nitrate of silver. Nitrate of silver may be prepared by adding pure silver to nitric acid, diluted with an equal volume of water; the action should be favoured by the application of a gentle heat. When the metal has dissolved, the solution should be evaporated, and the salt crystallized; the crystals must be dissolved in distilled or rain water, and lime water

added; a brown precipitate falls, which is the oxide of silver. The lime water must be added until it ceases to produce any further precipitation. The precipitated oxide should be collected, and well washed with pure water.

187. In order to prepare a solution of silver with the sulphite of potassa, the solution of sulphite of potassa—prepared as before described (179)—should be slowly poured into a solution of nitrate of silver, made by adding 12 ounces of the nitrate to 3 lbs. of water. A whitish precipitate falls, and the sulphite must be added until it ceases to produce a precipitate. The precipitate must be separated from the liquid, either by allowing it to subside, or by filtration, and must be well washed with water. It is then added to the solution of sulphite of potassa, until the solution will take up no more. As it is, however, desirable that the sulphite of potassa should be in excess, about one-sixth part of the sulphite of potassa solution should be added to the saturated solution.

188. The sulphite of silver is an excellent salt from which to precipitate silver; it is not liable to spontaneous decomposition like the cyanide and hypo-sulphite; it is less costly than the cyanide, and is unaccompanied by any unpleasant smell.

189. Hypo-sulphite of silver, as proposed by Mr. Talbot, may be made by adding chloride of silver to a solution of hypo-sulphite of soda (181) or potassa; oxide of silver, or any of the insoluble salts of that metal, may be substituted for the chloride. The chloride, or other salt, should be added till the solution will take up no more. Hypo-sulphurous acid has so great an affinity for oxide of silver, that all the soluble hypo-sulphites are decomposed by the salts of silver, giving rise to the formation of hypo-sulphite of silver. On adding a salt of silver to hypo-sulphite of soda, or potassa, a double salt, hypo-sulphite of soda, or potassa, and silver is formed, which is supposed to consist of one equivalent (35) of hypo-



sulphite of silver to two of the alkaline hypo-sulphite. The hypo-sulphite of silver itself, is insoluble in water. When dilute solution of hypo-sulphite of soda is added to dilute solution of nitrate of silver, a white precipitate of hypo-sulphite of silver is formed, which speedily re-dissolves from the formation of the double salt. The hypo-sulphite of silver may be advantageously used for the electrical precipitation of silver; it is one of the best solutions, though inferior to the sulphite and cyanide, and, like the latter, suffers spontaneous decomposition.

190. Sulphate of silver may be obtained by dissolving silver, by the aid of heat, in concentrated sulphuric acid. It may also be formed by adding sulphuric acid, or sulphate of potassa, to a solution of nitrate of silver; from its imperfect solubility in water it is precipitated as a crystalline powder, if the solutions are not too dilute. The salt is soluble in about 90 times its weight of water. A saturated solution must be employed; but it is inferior to many other solutions, and is not recommended.

191. Acetate of silver is formed by the addition of oxide of silver to acetic acid; or a solution of acetate of potassa to a solution of nitrate of silver. It is inferior, for electro-metallurgical purposes, to the sulphite and cyanide.

192. Many of the salts of silver, which are insoluble in water, dissolve in other menstrua, and may be used in electro-metallurgy. Chloride of silver, which is insoluble in water, is soluble in a solution of chloride of potassium, or chloride of sodium (common salt); and silver may be reduced from these solutions. Oxide of silver may also be dissolved in a solution of bitartrate of potassa (cream of tartar); but the solution possesses no advantages. Iodide of silver, obtained by adding iodide of potassium to nitrate of silver, may be dissolved in a solution of iodide of potassium, and in this way, be used for the deposition of silver. Mr. Spencer has proposed a solution of the bromide of silver in

acetate of ammonia. For this purpose, bromide of silver, which may be obtained by adding bromine to a solution of nitrate of silver, is added to about 30 times its weight of a saturated solution of acetate of ammonia, and the solution effected by the application of heat. Many other solutions of silver have been proposed, some of which, however, vary but little from those already described; and as these solutions possess no advantages which are not common to those already described, a description of them is unnecessary. The sulphite and cyanide, are superior to all the other salts of silver, for electric depositions.

193. Copper may be precipitated from a great variety of its salts; of which the most valuable are the sulphate, the nitrate, the sulphite, and the cyanide. Sulphate of copper may be made by dissolving copper in sulphuric acid, to which a small quantity of nitric acid has been added. The copper is oxidated at the expense of the oxygen of the nitric acid, and the sulphuric acid combines with the oxide so formed. Sulphate of copper is an article of commerce, and its preparation need not, therefore, be undertaken by the electro-metallurgist. The solution of sulphate of copper is not readily decomposed by a voltaic current of low intensity; and it is usual to increase its conducting power, by the addition of sulphuric or nitric acid, or a mixture of the two. Two parts of a saturated solution of the sulphate, and one part of dilute sulphuric acid (consisting of one-eighth concentrated acid), form a mixture, which practice has shown to be equal, if not superior, to every other. When it is desired to effect a rapid deposition of the metal, a little nitric acid should be added; the quantity must, however, be small, not exceeding one part to sixty or seventy parts of the cupreous solution.

194. Nitrate of copper may be made by dissolving copper, or scales of copper, in nitric acid, and crystallizing. Although a more expensive salt than the sulphate, it is much more valuable for electro-metallurgical operations; it suffers decomposition

more readily, so that a given quantity of copper may be deposited from it in a shorter time. A saturated solution of this salt may be conveniently used; and its conducting power, and, consequently, the rapidity with which it suffers decomposition, may be increased by the addition of nitric acid. One part of concentrated nitric acid to thirty parts of a saturated solution of nitrate of copper, form a solution, from which copper may be precipitated with greater rapidity than any other. A mixture of the solutions of sulphate and nitrate of copper has been proposed, and although it answers well, it has no peculiar advantages.

195. A solution, from which copper may be conveniently deposited, may be made with the sulphite of potassa solution (179). A solution of carbonate of potassa should be added to a solution of sulphate of copper, until it ceases to produce a precipitate. This precipitate is well washed, and added to the solution of sulphite of potassa, until it will take up no more. As it is desirable that the sulphite of potassa should be in excess, one-third more of its solution is added to the saturated solution.

196. Cyanide of copper is formed by adding oxide of copper to a solution of cyanide of potassium, until the solution is saturated. The application of heat facilitates the solution of the oxide. Oxide of copper may be prepared by exposing metallic copper, at a red heat, to the action of air. It may also be obtained by decomposing the nitrate by a red heat. For ordinary purposes, the cyanide is very inferior to the sulphate, nitrate, and sulphite; but occasions may present themselves in which it may be used with advantage. The same remark applies to the acetate, which may be made by digesting verdigris in acetic acid, and crystallizing. Instead of verdigris, oxide of copper may be used.

197. Oxide of copper is readily dissolved by ammonia, and the solution may be used for voltaic precipitation. It possesses no peculiar advantages.

198. Platinum may be deposited from a solution of its bi-chloride, bromide, iodide, and the double chloride of platinum and sodium.

199. Bi-chloride of platinum is formed by dissolving platinum in *aqua regia*. The latter consists of one part of nitric acid and two parts of hydro-chloric (muriatic) acid. The salt may be obtained by cautiously evaporating the solution. When redissolved, it forms a solution of an intense and pure yellow colour. It is the only salt of platinum, which is commonly used for voltaic precipitations.

200. Bromide of platinum may be obtained by digesting platinum in that highly divided state, in which it is called spongy platinum, in a mixture of equal parts of bromine and alcohol. The conducting power of the solution of bromide of platinum, may be increased by the addition of dilute sulphuric acid. The use of this salt was first proposed by Mr. Spencer.

201. Iodide of platinum, precipitated by iodide of potassium from chloride of platinum, and redissolved in excess of the precipitant, has been proposed for electric deposition; but it is inferior to the chloride, and the chloride of platinum and sodium.

202. Chloride of platinum and sodium, may be made by the simple addition of chloride of platinum to chloride of sodium.

203. Zinc may be reduced from its sulphate, chloride, iodide, and acetate, and the solution of its oxide in potassa, or muriate of ammonia (sal-ammoniac). Sulphate of zinc is formed, when impure zinc is added to dilute sulphuric acid. If pure zinc be used, some other metallic body must be brought in contact with it, otherwise it will not dissolve in the acid (50). The electro-metallurgist will rarely have occasion to make this salt, as it is formed in considerable quantity by the action of the common acid battery (110), and when crystallized from the acid, which has been used to excite the battery, is in a state of great purity. A saturated



solution of the sulphate, free from uncombined acid, may be used for the reduction of zinc.

204. Chloride of zinc, is formed when zinc is dissolved in hydro-chloric (muriatic) acid.

205. Iodide of zinc, may be formed by digesting together zinc, iodine, and water.

206. Acetate of zinc is formed when oxide of zinc is dissolved in acetic acid; the solution of this salt answers well, for the electrical reduction of the metal.

207. Oxide of zinc is a white powder, obtained by the combustion of zinc in an earthenware crucible; it may also be prepared by precipitation, from the sulphate, or any of its other salts, by the addition of potassa or soda. Oxide of zinc is soluble in ammonia, potassa, soda, and muriate of ammonia (sal-ammoniac), and its reduction may be effected from any of these solutions, The sulphate, however, is suitable for most purposes.

208. It has already been remarked (162), that all metals may be reduced from their soluble compounds, by the agency of voltaic electricity. There are few, however, excepting those already mentioned, which the electro-metallurgist will have occasion to operate upon, and it is therefore unnecessary to notice them in detail. Iron may be reduced from a solution of its proto-sulphate (green copperas), made by dissolving iron in dilute sulphuric acid; or from its proto-chloride, which is preferable, and which is made by dissolving iron in hydro-chloric (muriatic) acid. Lead may be reduced from its acetate (sugar of lead) and nitrate; and tin, from its sulphate and chloride.

209. Many of the salts used in electro-metallurgy, may be made by means of the voltaic battery itself. In order to produce any salt, it is only necessary to arrange the metal as the electrodes in a solution, from which, by voltaic decomposition, the element to be combined with the metal, may be liberated. Thus, in decomposing water with copper poles or electrodes, the oxygen liberated combines with the copper, and forms

oxide of copper (5); and if the water were acidulated with sulphuric acid, the oxide so formed would combine with the acid, and sulphate of copper would be the product. In this way almost all the salts may be formed; it is rarely, however, that they can be made so quickly, or so economically, as by the methods pointed out, and it is only where a salt cannot be conveniently made in the ordinary way, that its formation by the battery is recommended.

210. The cyanides of gold, silver, copper, &c., may be formed by passing a voltaic current through a solution of cyanide of potassium, the electrode in connection with the silver or copper end of the battery being of gold, silver, copper, &c., the other electrode may be of the same metal, or of platinum. Mr. Spencer has proposed to make the iodide and bromide of gold, and the iodide and bromide of silver, by means of the voltaic battery. The following is the plan he adopts:—to make the bromide of gold; make a mixture of equal parts of bromine and alcohol; and of this mixture take one part, of acetic acid one part, and four parts of water. To this mixture let a few drops of sulphuric acid be added. Gold may be dissolved in this mixture by attaching it to the platinum, or copper end, of a voltaic battery; while another piece of gold is, in like manner, attached to the zinc end of the battery. These pieces of gold must be immersed in the compound containing the bromine; and when the battery is excited into action, the gold attached to the platinum end of the battery will be dissolved. When the mixture is saturated with gold, it should be diluted with three times its volume of water, and a few drops of sulphuric acid added. Mr. Spencer also describes a solution of gold, made in the way just described, combined with an ammoniacal salt; two parts of a saturated solution of acetate of ammonia should be added to one of the solution of bromine. When the metal required to be gilt is of such a nature as to act on the solution of gold and bromine by mere immersion, Mr. Spencer directs the

addition of carbonate of soda, till the solution will take up no more.

211. Silver may be dissolved in a saturated solution of acetate of ammonia, by means of the voltaic battery, and this solution may be used for electro-metallurgical purposes; and the same metal may be dissolved in bromine, in the following manner:—A mixture is made of bromine and alcohol; and plates of silver, connected with the poles of a galvanic battery, are immersed in the mixture. By the action of the battery, that plate of silver connected with the platinum or silver end of the battery is dissolved in, and combines with, the bromine. On setting aside the solution, a yellow precipitate of bromide of silver falls to the bottom of the vessel. The fluid is decanted from the precipitate, and the latter is dissolved by boiling, in thirty times its weight of a saturated solution of acetate of ammonia.

## CHAP. VII.

## ON THE PREPARATION OF SURFACES FOR RECEIVING METALLIC DEPOSITS.

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212. It is essential that the surface on which it is wished to deposit a metal by electro-metallurgical agency, be a conductor of electricity (46).

213. It has already been remarked (46), that the only conductors are metals and charcoal; and it is, therefore, only on those bodies that metallic precipitations can be effected by the agency of electricity: and when it is wished to precipitate upon a non-metallic or non-conducting surface, it is necessary to give, by some preparatory process, a film of metal or charcoal, to the article intended to receive the deposit.

214. These metallic or carbonaceous films may be produced on non-conducting bodies by a variety of processes. The earliest process is that of Mr. Spencer; and the following account is in his own words:—"I procured two models of an ornament, one made of clay, and the other of plaster of Paris, soaked them for some time in linseed oil, took them out, and suffered them to dry, first getting the oil cleared off the surface. When dry, I gave them a thin coat of mastic varnish. When the varnish was nearly dry, *but not thoroughly so*, I sprinkled some bronze powder on that portion I wished to make a mould of. This powder is principally composed of sulphur and mercury, or it may be chemically termed a sulphuret of mercury. There is a sort that acts



much better, in which is a portion of gold. I had, however, a complete metalliferous coating on the surface of the mould, by which I was enabled to deposit a surface of copper on it by the voltaic method I have already described. I have also gilt the surface of a clay model with gold leaf, and have been successful in depositing copper on its surface. There is likewise another, and, as I trust it will prove, a simpler method of attaining this object; but, as I have not yet sufficiently tested it by experiment, I shall take another opportunity of describing it." The method here alluded to was afterwards given by Mr. Spencer, in the following words:—"To obtain a copper mould, or cast from a-piece of wood, plaster, or clay, or, indeed, any non-metallic material, proceed as follows:—Suppose it to be an engraved wooden block which you are desirous of metallizing, in order that copper may be deposited on its surface—this example holding good for any other material. The first operation is, to take strong alcohol, or spirits of turpentine, in a glass vessel, and add to it a piece of phosphorus (a common corked phial will answer the purpose); the vessel must now be placed in hot water for a few minutes, and occasionally shaken. By this means the alcohol will take up about a three-hundredth of its bulk of phosphorus, and we thus obtain a solution of phosphorus. Next, procure a weak solution of nitrate of silver, place it in a flat dish or saucer; the engraved face of the block must now be dipped in this solution, and let remain for a few seconds to allow capillary attraction to draw the nitrate of silver into the wood. This operation being performed, a small portion of the solution of phosphorus must be placed in a capsule or watch glass, and this be placed on a sand-bath, that it may gradually evaporate. The block must now be held with its surface over the vapour, and an *immediate change* takes place; the nitrate of silver becomes deoxidised, and gives place to metallic silver, which allows the voltaic deposit to go on with as much rapidity and certainty as the purest

silver or copper. The whole process may be performed in a few minutes, and with absolute certainty of success. The interior or exterior surface of a plaster or clay mould of a statue, no matter what size, may be thus metallized with equal facility. For the process of vaporizing, when the material to be acted on is not very large, fasten it to the top of a bell-glass receiver, with a bit of pitch or cement, and place it thus over the capsule on the sand-bath; the phosphoric vapour is by this means equally diffused, and not dissipated. A solution of phosphorus in sulphuric ether also answers; and a solution of chloride of gold may be used."

215. This elegant process, as applied to wood, and those substances which can be wetted with the solution of nitrate of silver, answers perfectly; but it is obviously limited in its application to such substances as will absorb an aqueous solution.

216. This plan has recently been modified with advantage. Instead of the vapour of phosphorus, a solution of that substance is now commonly used. The best solvent of phosphorus hitherto known is bi-sulphuret of carbon.

217. Bi-sulphuret of carbon may be prepared in two ways. A cast-iron or porcelain tube, or vessel, is filled with small pieces of charcoal, and heated to redness in a furnace. This tube, or vessel, is connected at one end with a retort, or second vessel, containing sulphur; and at the other with a condensing apparatus. Heat is applied to the vessel containing the sulphur, which is thus volatilized, and, in its passage over the red-hot charcoal, combines therewith, to form the compound in question. The vapour is conducted through a tube to the bottom of a vessel containing water, by which it is condensed.

218. Bi-sulphuret of carbon may also be formed by distilling a mixture of four parts of bi-sulphuret of iron, or pyrites, with one-part of charcoal. The ingredients should be in a state of fine powder, and intimately mixed.

219. Bi-sulphuret of carbon is a colourless liquid of a peculiar odour; it reflects light powerfully; it burns with a beautiful blue flame; and gives out, during combustion, intense heat. It is very volatile, and produces intense cold by its evaporation. As it is heavier than water, and is not miscible with it, it is best preserved from wasteful evaporation, by a stratum of water on its surface. This substance dissolves phosphorus in very large quantity; it is, however, advisable not to use the saturated solution, as a much thicker film of phosphorus, would in that case be left, than is necessary. A solution, commonly used, is made by dissolving one part of phosphorus in twelve parts of bi-sulphuret of carbon. The articles to be coated should be dipped, for a moment, in this solution; on removal, the bi-sulphuret of carbon, which is very volatile, quickly evaporates, and leaves a film of phosphorus on the article. If the cast, or mould, be now immersed in a solution of sulphate of copper, a precipitate of copper is immediately formed on it; it is, however, preferable to use a dilute solution of nitrate of silver. From this solution a film of silver is immediately precipitated; and the surface of the article being now a perfect electric conductor, may be introduced into the solution, and treated in every way as a metallic article. The surface of an article before immersion in the solution of phosphorus, should be perfectly free from water. By the use of this solution the most delicate matters may be covered with metallic films by electric deposition; lace, feathers, insects, preserved birds, fruit, and indeed, any article which will bear immersion in a liquid.

220. The solution of phosphorus in bi-sulphuret of carbon should be very carefully used, as any drops allowed to fall about, may occasion serious accidents. This solution is, under some circumstances, spontaneously inflammable; its inflammation, too, is sometimes delayed a considerable time. If a piece of dry paper be dipped into a solution of phosphorus in bi-sul-

phuret of carbon, and laid aside, it will, after the sulphuret has evaporated, first give off a dense white vapour, and afterwards inflame; from five minutes to half an hour (depending on the strength of the solution) elapse before this inflammation occurs.

221. An improvement in the preparation of non-metallic surfaces has recently been introduced, by which much of the inconvenience attending the usual methods of preparation is avoided. It consists, in forming the cast, or mould, on which the deposit is to take place, of a compound containing phosphorus. A mixture of wax or tallow with phosphorus answers admirably. As phosphorus will not mix with wax or tallow by the simple addition of one to the other, the following method of mixing them must be resorted to. The phosphorus is dissolved in bi-sulphuret of carbon, and the solution introduced into the wax or tallow while the latter are in a state of fusion. The utmost precaution must be employed in preparing this compound; the extreme inflammability of the solution of phosphorus in bi-sulphuret of carbon, at ordinary temperatures, is a source of great danger; but when, as in the preparation of this compound, its temperature is considerably raised, it is necessary to conduct every part of the process with extreme care. The wax or tallow should, after melting, be allowed to become as cool as is compatible with tolerable liquidity; and in that state the solution of phosphorus should be introduced into it. The solution should be contained in a vessel having a long spout, which can be plunged under the surface of the melted wax or tallow, so as to deliver it at the bottom of the vessel. The phosphoric solution should be slowly poured into the liquid wax with one hand, while with the other the intimate mixture of the liquid is effected, by constant stirring with a glass rod. The stirring must be continued until the solidification of the wax or tallow has commenced. One ounce of the solution of phosphorus (219) may be added to each pound of wax. The



mixture smells strongly of phosphorus, and when freshly cut is luminous in the dark. A cast taken with this mixture, immediately becomes covered with a metallic film, on immersion in a dilute solution of nitrate of silver, and requires no other preparation, previous to its introduction into the precipitating trough.

222. The mixture of phosphorus and wax or tallow, may sometimes be conveniently substituted for the solution of phosphorus, in bi-sulphuret of carbon. In order to give a conducting surface to a non-conductor, the latter may be dipped into the melted mixture; on being withdrawn slowly, it retains a thin film, which, by immersion in the dilute solution of silver, immediately precipitates a metallic coating.

223. It is necessary in using this mixture to stir it frequently, while in the melted state; otherwise, the phosphorus slowly separates, and collects at the bottom of the vessel.

224. For the purpose of rendering the surface of any small article of wax, or plaster of Paris, an electric conductor, the process of Mr. Murray may be resorted to. It consists in covering the surface of the mould with plumbago, or, as it is commonly called, black lead. If the mould or surface is of wax, all that is necessary, is to brush the powder slightly over the surface with a soft camel-hair pencil; a very small quantity will adhere, and will communicate to the wax that metallic appearance so characteristic of plumbago. An exceedingly thin coating is attached, so thin indeed, as scarcely to be visible, excepting by reflected light. This is sufficient for every purpose, and is even to be preferred to the thicker coating that may be given by several applications.

225. The process of black-leading is equal to any process which has yet been made known. It is applicable to every substance likely to be used for the manufacture of moulds: wax, wood, plaster of Paris, sealing wax, are equally susceptible of receiving a coating of this substance. Much difference of opinion has existed relative to the value of Mr. Murray's

process ; some have highly extolled it, while others have been loud in condemning it. These contradictory opinions are explained by the fact, that there is a great difference between one specimen of black lead and another ; one sample appears a perfect conductor, while another is an equally perfect non-conductor ; and it is only by actual experiment that its quality can be determined.

226. The treatment by phosphorus gives an actual coating of metal to the article ; and hence, when an article so treated is introduced into the electro-metallurgical apparatus, an immediate deposition commences over the whole surface. With black lead, however, it is otherwise ; the deposition commences at the wire, by which the article is connected to the battery, and around that, as a centre, the metal spreads in every direction, until the whole surface is covered. Unfortunately, this beautiful process is limited to copper, as that is the only metal in common use which will spread on a black-leaded surface. Silver and gold spread to so limited an extent, that the process is inapplicable with those metals.

227. The surface on which electric deposition is to take place, must not only be a conductor of electricity, but it must also receive such a preparation previous to use, as will determine the adhesion of the deposit, or its non-adhesion, as the case may be.

228. In depositing on metallic bodies, from which we wish the deposit to separate, as in the copying of engraved copper-plates, medals, coins, and metallic moulds, the surfaces of these articles must be prepared so as to prevent the adhesion of the metal ; when the metal deposited is the same as that on which it is thrown down, there is greater danger of adhesion than when the metals are dissimilar. A piece of metal (copper, for example) by immersion, first in an alkaline, and afterwards an acid solution, becomes chemically clean ; and copper deposited on such a piece of copper would adhere, and form one with it. If, however, the copper so cleaned be

left simply exposed to the air for several hours, especially in a cold situation, its surface receives some change, by which the copper deposited on it, by an electro-metallurgical process, has so feeble an adhesion, that the application of a slight force suffices to detach it. The nature of this change in the character of the surface, is not well understood; it is by some supposed to be a slight oxidation, or some change of a chemical nature; while by others it is regarded as the condensation of a film of air on the surface of the metal. We may avail ourselves of this state of surface to prevent the adhesion of the deposited metal; and to do so, we must be careful not to rub it, nor expose it to acids, or alkaline solutions. This state of surface is also destroyed by heat; it is, therefore, absolutely necessary, if the wire which connects the plate to the battery has been soldered to it, or the plate otherwise heated, to allow it to remain many hours exposed to the air in a cool situation; for if it be introduced into the apparatus immediately after having been heated, the precipitated copper will adhere so as to resist all attempts to remove it; but, after the treatment above recommended, there is much less disposition to adhesion. Still, the introduction of a plate into the apparatus, under such circumstances, is not unattended with risk; and it is advisable always to adopt the simple and efficacious plan recommended by Mr. Spencer, which will be found perfectly effectual in preventing the adhesion of the deposit.

229. The surface on which the deposit is to take place, should be heated and rubbed with bees' wax until every part has received a coating; the wax should be thoroughly melted, and, after having remained a few minutes on the surface, be carefully wiped off with a linen rag; when cold, it may be introduced into the electro-metallurgical apparatus without fear of adhesion. In cleaning off the wax, care should be taken not to leave any portion uncleaned; in such a case, no deposit will take place on the coated part.

Where the surface to be deposited upon is not of extreme delicacy, the following method may be adopted for preventing the adhesion:—the article should be immersed in some solution that will deposit upon it a thin film of a dissimilar metal—the cyanide of silver, for example, which, in a few seconds, will give it a thin coating of silver; or it may be connected with the battery, as hereafter described, so as to obtain a thin coating of that metal; the deposited metal, being separated from the original surface by a thin film of silver, will readily separate. Copper reduced in the electrotpe may become one with the copper on which it is deposited, or silver with silver; but dissimilar metals are with difficulty made to unite firmly.

230. The electro-metallurgist sometimes wishes to effect the adhesion of the precipitated metal to the surfaces on which it is deposited; as in the deposition of films of gold and silver in plating articles, and in defending iron, and other metals, by means of coatings of copper and zinc. In such cases, the utmost attention must be paid to the cleanliness of the articles which are about to receive the deposit. When practicable, a slightly rough surface should be given to the articles, either by the chemical process called “dipping,” or by the mechanical process called “scratching.” It often happens that the nature of the articles will not admit of this rough surface, and when thin films of metal are to be deposited, it is obviously impracticable; in such cases the end must be attained by carefully cleaning the surface.

231. The most effectual cleaning is effected by immersion in an acid liquor, called “dipping liquor.” The composition of this liquid is as follows:—

Sulphuric Acid	.	.	.	.	.	.	64
Nitric Acid	.	.	.	.	.	.	32
Hydro-chloric (muriatic) acid	.	.	.	.	.	.	1
Water	.	.	.	.	.	.	64



If the surface of the article to be cleaned, is covered with oily or greasy matters, the process of dipping will be of little avail, the metal being effectually defended from the action of the acid, by the film of greasy matter. In such cases it is necessary to remove the oil, or grease, before the process of dipping. This may be done in a variety of ways; the most convenient, and a very effectual one, is that of boiling the articles in a strong solution of pearlash; after such treatment, the dipping acid will take effect.

232. Metallic surfaces may be made clean by means of the voltaic battery. It has been already more than once stated (6), that when a metal, having an affinity for oxygen, is connected with the copper or silver end of the battery, and made one of the electrodes in an acid or saline solution, the oxygen evolved there by the passage of the voltaic current, combines with the metal, and forms an oxide; an excellent method of cleaning surfaces to receive voltaic deposits, is founded on this fact. In order to clean a metallic surface by means of the battery, the article must be attached by a wire to the copper, or negative metal, of the instrument; and a metallic surface, at least equal in area to that of the article to be cleaned, must be connected with the zinc. The metals must be plunged in an acid or saline solution, when decomposition of the water will take place. The oxygen evolved will combine with the metal of the article to be cleaned; and this oxide will be dissolved by the acid, or other solution employed. Articles may thus be cleaned in two or three minutes. This plan possesses the advantage of great uniformity; it is impossible by any process of scouring, to treat every part of an article equally; but by the foregoing process a minute film is removed from the whole of the surface. The solution to be employed for this process of cleaning must be varied to suit the metal, or alloy, of which the article to be cleaned is made. All that it is necessary to observe is, that the solution should be one which has no action on the metal

of which the article is composed, but which will dissolve the oxide or salt formed. For copper articles, a solution of sulphate of copper, slightly acidulated with sulphuric acid, may be employed; for silver surfaces, a solution of cyanide of potassium, or, by preference, of sulphite of potassa; for iron, a saturated solution of sulphate of soda has been recommended by Mr. Spencer. A battery of two or three cells

should be used in this process.

233. Some metals, when immersed in the solutions by which they are to be coated, receive a film of metal without the application of the battery; thus, when copper is introduced into the cyanide of silver, a film of silver is deposited immediately on immersion, the copper dissolving in equivalent quantity (35), and taking the place of the silver in the cyanide. In such cases the difficulty of securing the adhesion of the precipitated metal is increased, for the quantity of metal dissolved is small, and the impurities with which all metals manufactured in the ordinary way abound, are left on the surface, and the adhesion of the silver prevented. This difficulty may, to a considerable extent, be got rid of, by scouring the articles with the solution, previous to introducing them into the depositing vat. For this purpose, a quantity of Calais sand, wetted with the cyanide solution, should be taken on a scratch brush (an instrument made by binding together a great number of fine wires), and the article should be well scoured in this way, until it has a coating of silver, when it may be put into the precipitating, or depositing vat. The film of silver thus produced, adheres more closely than that obtained by mere immersion.

234. The electro-metallurgist, however, finds great difficulty in producing a perfect adhesion, even where the utmost precautions are taken. The cause of this difficulty is obvious: all the processes hitherto noticed, have for their object the production of a perfectly clean surface; and when that is obtained, all that can be effected, is the deposition of the metal

in intimate contact with that of the article to be coated. But the metals are simply in contact, there is no alloy; and, in this respect, the plating by electric agency is defective. In the ordinary method of plating, where an ingot of silver is attached to one of copper by fusion, there is an alloy; that is to say, the silver is united to, and forms one with, the copper; but in electro-metallurgical plating, there cannot be any such junction.

235. Such are the difficulties that have presented themselves in obtaining, with certainty, the necessary adhesion between the metals, that the most experienced operators in the art, despair of ever being able to produce sufficient adhesion, by any process of cleaning the surface to be plated. Nothing short of an actual alloy between the two metals, suffices to prevent the occasional detachment of the deposit.

236. A film of mercury is now commonly used for the purpose of alloying the two metallic surfaces; the liquid metal is applied in the following manner:—Mercury (quicksilver) is dissolved in nitric acid slightly diluted with water. The solution is set aside to crystallize, and the crystals of nitrate of mercury are dissolved in water. A solution, containing an ounce of mercury to a gallon of water will be found very convenient; but the exact strength of the solution is not of much consequence.

237. When a piece of copper, or of an alloy of copper, is plunged in a solution of nitrate of mercury, the former metal becomes immediately covered with a film of the latter. The thickness of this film is dependent on the time during which the copper is immersed in the mercurial solution. The cause of this precipitation of mercury, is the decomposition of the nitrate by the copper; the oxygen and nitric acid of the mercurial salt have a greater affinity for the copper than for the metal with which they are combined, and hence quit the mercury to combine with the copper; the liberated mercury attaches itself to the metal by which it has been set free.

238. The film of mercury which may be thus deposited on a metallic surface, is sufficient to effect the most perfect adhesion between the metal of the article under experiment and the film deposited on it; for the mercury amalgamating with both metals, acts precisely as a stratum of solder between them, completely alloying their surfaces. The quantity of mercury requisite to produce this effect is exceedingly small, indeed it is scarcely possible to use too small a quantity, and too large a quantity should be most carefully avoided; if too much mercury accumulates on the metal, the amalgamation which takes place gives a roughness to it, which, in most cases, it is desirable to avoid; and the deposited film is sometimes injured, by the mercury amalgamating with it to such an extent, as to penetrate it and appear on the surface of the plated article, so as to injure its colour. The mercury may, indeed, be dissipated by the heat which is generally applied to the plated articles; but even in that case, the excess of mercury leaves the surface rough. In using the nitrate of mercury, the articles, after having been properly cleaned, should be dipped for a few seconds into the nitrate of mercury, and on removal, passed through water to remove any trace of the solution, and should be introduced into the precipitating vat as quickly as possible. Immediately after the articles have been plated, they should be heated to a temperature of about  $600^{\circ}$  F., in order to dissipate the mercury.



## CHAP. VIII.

ON THE PRODUCTION OF MOULDS, OR SURFACES, TO  
RECEIVE ELECTRO-METALLURGICAL DEPOSITES.

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239. THE electro-metallurgist frequently has occasion to produce *fac-similes*, both of metallic and non-metallic articles; for this purpose, it is necessary to procure impressions or moulds of the articles in question, and by depositing metal in the interior, or on the exterior of such moulds, to produce the desired copy. Moulds may be made either of metallic or non-metallic substances; the form of the original article, and the material of which it is made, must determine which of the methods hereafter described is most applicable in any particular case.

240. In copying coins, medals, or plates, or objects of which it is wished to copy only one surface, we may introduce them at once into the solution, and, by procuring a deposit upon them, obtain a mould, which will afterwards serve to receive another deposit, the *fac-simile* of the medal. It is necessary to remark that the bronze appearance of a medal is sometimes injured by this mode of proceeding; of all methods of copying coins or medals by electricity it is the worst, and should only be adopted in those cases where slight injury to the coin or medal is unimportant. A much better way is to take moulds of the coin or medal, and procure a deposit in them. In copying engraved plates, or large subjects the surfaces of which are not of so delicate a

nature as those of medals, the preceding process is, however, exceedingly convenient.

241. For small plates and coins, moulds may be readily made in lead, and there is no risk of adhesion between this metal and the copper; such moulds need no preparation. If the medal, or other subject to be copied, be not very prominent, impressions of either side (in case of a medal) may be procured by simply placing it between two pieces of sheet lead, the surfaces of which have previously been made clean by scraping, and subjecting it to the action of a press. Mr. Spencer suggests that a number of coins be placed between two strips of lead, and these passed through a copper-plate printer's press. A series of impressions will thus be produced, and, by placing these strips in the voltaic apparatus, a sheet of electrotype casts will be obtained, or, by varnishing the space between the impressions, they will be separated. This plan, however, will not succeed in subjects the surfaces of which are prominent. Moulds from these must be obtained by casting, either in fusible alloy, wax, plaster of Paris, &c. The alloy known by the name of Newton's fusible metal, and consisting of about eight parts of bismuth, four of tin, and five of lead, may be used; but the composition will be much improved if one part of antimony be added; this mixture must be melted repeatedly, and poured in drops, in order to effect a perfect uniformity in the composition. It fuses at a low temperature, and a lamp is a very convenient means of melting it in small quantities. In using this alloy, it is well to melt it with the application of as little heat as possible, and, after having stirred it, to pour a quantity either upon paper placed upon a flat surface, or on a non-metallic surface, slightly concave. It may be stirred about with cards until it approaches the solidifying point, when the medal is to be pressed upon it in the manner which will be hereafter described. The stirring, however, is not necessary, for the most perfect casts may be obtained by simply pouring out the

metal and, after having drawn lightly over its surface the smooth edge of a card, held in an inclined position, applying the medal thereto just before it is about to solidify. The exact point of time is essential; if it is placed upon the fluid metal while too hot, the cast will be deficient in that sharpness and brilliant surface essential to perfection—and, if too cold, an imperfect impression will be the result; the moment when the metal is assuming that crystalline arrangement which is the first step to solidification, is the best time for the application of the medal. In order to ascertain this time, we have only to look closely at the surface of the liquid metal. At first, a picture of the surrounding objects will be reflected from it with the utmost accuracy; in a few moments, the edges of the melted mass appear less bright, and eventually the whole surface partakes of the same character. A number of points appear to be rising upon the surface, and thus destroy the accurate reflection of objects. It is at this stage that the medal should be suddenly brought down upon it in a horizontal position, and with such force as to bury half its thickness in the alloy. In order to bring the medal down in a horizontal position considerable care is requisite, and, even then, unless assisted by some mechanical contrivance, it is exceedingly difficult. Much of the uncertainty of the process may be removed by attaching the medal to some support, which affords firm hold for the hand—a rod or cylinder of wood, for example. It is unnecessary to enlarge on this subject, as a variety of ways of accomplishing the same object will occur to the experimenter.

242. Alloys of different degrees of fusibility may be employed. Either of the following may be used instead of Newton's:—An alloy of fourteen parts of bismuth, sixteen of mercury, and thirty-two of lead, which melts in boiling water; as also does an alloy consisting of four parts of bismuth, four of lead, one of tin, and one of mercury. The following requires a heat somewhat higher than that of boiling water

for its fusion :—two parts of lead and one of bismuth ; as also the alloy formed of three parts of bismuth, six of lead, and one of antimony.

243. In using fusible alloys in large quantities, it is most convenient to heat them over a lamp or gas burner, in a vessel having a tap at the bottom, so as to allow the lower portion of the metal to run out, and thus avoid the scum, or oxide, on the surface.

244. Moulds of extreme beauty may be made of wax and other similar substances, such as stearine and tallow. Moulds of wax are formed very readily. The medal should be slightly smeared with olive oil, and a slip of paper fastened around it. The melted wax is poured over it, and allowed to cool. It is desirable to have the medal warmed, and the wax should be allowed to become so cool as to set soon after it is poured on. If either of these conditions be neglected, the experiment will be unsuccessful. If the medal is not warmed, the wax will be suddenly chilled, and the mould will present a waved appearance ; and if the wax is used too hot, the oil becomes incorporated with it before setting, and the cast cannot be removed.

245. Casts of plaster medallions may be taken in wax by a process of extreme simplicity. The plaster model is to be placed in warm water, and allowed to remain there until it ceases to absorb it. It may then be removed, and, after the water has disappeared from its surface, the wax may be poured over it. Immediately it has cooled, it may be removed without the slightest difficulty. Moulds, if thus procured, are of singular beauty ; and, if the plaster model has been properly prepared, it is not in the least injured by the application of the warm water. If it be made of bad plaster, small portions of it will probably be detached, and will be found adhering to the wax mould ; these may be removed by the application of dilute sulphuric acid ; after a short time a camel-hair pencil will clear it away.



246. Moulds may also be formed of plaster of Paris. The manner of operating with this substance is so well known, that a detailed account of it, is unnecessary. Powdered gypsum, or sulphate of lime, when heated to a proper temperature, possesses the remarkable and valuable property of forming with water, a hard solid. The powder is mixed with water so as to have the consistence of thick cream, and, after having been stirred to remove the bubbles arising from the air which had been lodged in the plaster, it is poured on the medal, or object to be copied, which, when necessary, should be slightly oiled. After the lapse of a few minutes, the plaster will be so hard that it may be safely removed; but it requires a much longer time to attain its greatest hardness.

247. In those cases where it is necessary to produce copies of busts, vessels, and elaborate works of art, a more complex method of preparing the models or moulds to receive the deposite, must be resorted to. In order to produce *fac-similes* of such objects, the electro-metallurgist may adopt either of the following methods: he may prepare a hollow mould of the object, that is to say, such a mould as would completely encase the object to be copied, and deposit metal therein; or he may obtain a model, by casting, exactly resembling the object to be produced, and deposit a thin film of metal thereon; the internal model may be removed as soon as the metallic film is sufficiently strong, and metal deposited in the interior, so as to give the object the desired strength. The former method produces the most perfect results.

248. To produce a mould in which it is intended to deposite internally, the following course should be pursued:—The operator must first prepare a mould of the article to be copied, in plaster of Paris. This mould is made in the usual manner, that is to say, in parts that can be separately removed from the model on which they have been cast. The model being enclosed in its mould, the operator proceeds to remove one of the pieces of which the mould is formed, and pours

into the vacant space the melted fusible alloy (242), wax, or other material of which he intends to construct the mould to be deposited on. When the liquid metal or wax has cooled, it is removed, and forms a portion of a mould, exactly resembling the plaster portion, in whose place it has been cast. This portion of the plaster mould is replaced, and a second portion is removed, and the vacant space left by its removal, filled up by the melted alloy or wax; and in this way every portion of the plaster mould is, in turn, removed, and a corresponding metal or wax portion cast in its place. A complete mould of the article to be copied is thus produced. The various parts of which the mould is composed, must be securely held together by being bound with wire, or otherwise. When the object to be copied is made of a material that will not admit of the application of the heated metal or wax, plaster of Paris may be employed. If metal be used, the exterior surface must be treated in the way pointed out in another part of this chapter (256), in order to prevent a deposit taking place thereon; and if wax, or plaster of Paris be employed, their surfaces must be rendered conductors of electricity, by the means pointed out in the last chapter.

249. The method just described may, under some circumstances, be conveniently modified. By this process, a mould is procured, in which a number of copies may be made; but where it is only desired to make one copy of an article, the following method may be conveniently substituted:—the mould, cast in portions on the object to be copied, should be removed from the object, and melted wax, or fusible alloy, poured therein. If the operator uses wax, the plaster should be saturated with warm water (245), to prevent its absorption and adhesion. The mould should be moved about until the wax is cold, so as to produce a uniform coating on every part of it. If fusible alloy be employed, a core of wood or plaster, should be introduced into the hollow mould, so as

to diminish its capacity, and the fused metal poured into the space between the core and the mould.

250. By these means a model is obtained in wax or fusible alloy, exactly resembling the object of which a copy is to be formed. The next step in the process, is the formation of a mould on this model. This may be done by electric deposition; the model being connected, in the manner described in another part of the treatise, with a battery and precipitating trough, quickly receives a deposit of copper. When the copper coating is deemed sufficiently thick, it may be removed from the precipitating trough, and the wax, or fusible alloy, removed from its interior by fusion. The interior of this mould having been properly cleaned (227), and its exterior defended (256), it is ready to receive an electro-metallurgical deposit. This process is peculiarly adapted to the production of copies in gold and silver, as in case any difficulty occurs in tearing the copper mould from the electric deposit, it may be readily removed by chemical means. Per-chloride of iron possesses the valuable property of dissolving copper, tin, lead, &c., but is without action on gold and silver; hence, when any adhesion takes place between a copper, tin, or lead mould, and a gold and silver deposit thereon, the copper, tin, or lead, may be dissolved, by immersion in a solution of per-chloride of iron, and the gold or silver article preserved.

251. Per-chloride of iron may be formed by dissolving per-oxide of iron (colcothar) in hydro-chloric (muriatic) acid.

252. Per-oxide of iron may be procured by adding nitric acid to a boiling solution of proto-sulphate of iron (green copperas), and precipitating by the addition of ammonia; or more readily, by decomposing the same salt (green copperas), at a high temperature. Sulphuric and sulphurous acids are driven off, and per-oxide of iron remains.

253. When the solution of per-chloride of iron is saturated with copper, ammonia added precipitates the per-oxide of

iron; and this, when separated by filtration, may again be dissolved in hydro-chloric (muriatic) acid, so as to form the per-chloride.

254. In obtaining copies of works of art, by depositing on the external surface of a mould or model, it is only necessary to obtain a model in wax, or fusible metal, exactly resembling the object to be copied. This mould may be made by the method already described (248), and after having rendered its surface (if made of wax) a conductor of electricity, it may be placed in the precipitating vat, so as to receive a deposit. The action of the battery should be regulated so as to deposit slowly, in order to preserve the surface of the metal, smooth. When a sufficient thickness of metal has accumulated, the internal model may be removed by heat, or otherwise. The deposit may be strengthened to the required degree, by reducing metal in the interior, the exterior having been previously defended.

255. When the object to be copied has over-hanging parts, it is obviously impossible to remove the mould cast on it, unless it be made in so great a number of parts, as to render it inconvenient in use. This difficulty has suggested the use of an elastic material for the construction of moulds, which will yield, so as to admit of its removal from intricate parts, and afterwards regain its proper form. The most suitable materials for the construction of elastic moulds, are glue, and a mixture of glue and treacle. When it is intended to use the mould soon after it is made, glue answers in every respect, but moulds made of glue alone, soon become hard, and lose their form; in order to avoid this difficulty, treacle should be mixed with the glue. To make a mould of glue, the article should be surrounded with a case of any convenient material, and the melted glue, as thick as it can be used, should be poured on the article, so as to fill up the space between it and the surrounding case. When the glue is quite cold, it should be cut into as many pieces as may be



thought desirable, and the mould thus removed. If the article is of plaster of Paris, or any substance likely to absorb the glue, it should be slightly oiled, previous to pouring the glue on it. Models in plaster of Paris and wax may be cast in glue moulds. In casting wax models, care should be taken to have the wax as cool as is compatible with the requisite degree of liquidity.

256. Moulds of plaster of Paris require a particular preparation, before they can be rendered conductors of electricity, by the application of black lead (224), or a metallic film, precipitated by phosphorus (219). The porosity of plaster of Paris is such, that without such preparation, when put into the solution, it will absorb the liquid, and the air, which previously filled its pores, will be expelled, and the mould will be covered with small bubbles, which obviously render it unfit for the reception of the metallic deposit. In order to prepare the plaster for experimenting in the electro-metallurgical apparatus, it is necessary to fill its pores with some substance insoluble in water, and capable of resisting the action of the metallic solution. The various substances that will answer this purpose, are wax, tallow, spermaceti, linseed oil, and varnishes. As wax answers in every respect, and is superior to the other substances enumerated, we shall content ourselves with noticing its application. The wax should be well melted, and the plaster mould (which must be perfectly dry,) should be immersed in it, and allowed to remain some minutes: it may then be removed, and placed, with its face upward, in a warm situation, until the liquid wax has disappeared from its surface; when it may be allowed to cool. The black lead should be applied, as in the case of wax, with a soft brush, or the solution of phosphorus, in the way already explained (219).

257. In those cases where a metal mould is used, it will be necessary to cover with wax, varnish, or some other non-conducting material, those parts of the mould where the

deposited metal is not required. This coating of the back and other parts requires to be done with care : if the smallest portions be exposed, they will receive a coating of metal, which is so much waste. Nor is this the only inconvenience—for if the edge of the mould is left uncoated, the metal spreading on it, will render the removal difficult, inasmuch as that part must first be cut away ; and it rarely happens that, under such circumstances, the mould escapes wholly uninjured.

258. The material most commonly employed for coating metallic surfaces, where it is wished to prevent a deposit of metal, is caoutchouc, or India rubber ; and the most effective solvent of this substance, is bi-sulphuret of carbon (217).

259. A convenient solution is made by adding one part, by weight, of caoutchouc, to four parts of bi-sulphuret of carbon. The solution should be kept under water. It may be applied with a brush, and must be spread quickly, as, from the volatility of the sulphuret of carbon, it soon becomes hard.

260. The precaution of coating, with a non-conducting substance, those parts of a mould on which it is wished to prevent a deposit, is obviously limited to metal moulds ; as those made of wax and plaster of Paris are themselves non-conductors, and only receive a deposit on those parts which have received a coating of conducting material (213).

261. The first step, after the preparation of the mould, is the attaching of a wire to it. If the mould is of fusible alloy, the wire may be readily attached by holding it for a few seconds in the flame of a candle, and melting it into the substance of the metal ; or a hole may be made in the edge of the mould, and the wire being bent in the form of a hook, introduced in it, and the mould thus suspended in the solution. If the mould or design is of wax, and its surface has been prepared for a deposition of copper, by black lead (224), a wire should be melted into its edge, and the black-

lead brush rubbed around the wire and the edge of the mould, so as to make a continuity of the black-leaded surface from the wire to the surface of the mould; if of plaster of Paris, the edge, as well as the surface of the mould, should be black-leaded, and a thin wire twisted round it; if the mould or plate is of lead, the wire should be soldered to its back. As it is desirable, in depositing copper on a black-leaded surface, to cause the deposition to go on with as great rapidity as possible, contact between the surface and the connecting wire should be made in several places, especially if the surface be a large one. The cases in which this can be done without risk of injury to the mould, must be determined by the operator. Whatever plan of attaching the wire is adopted, it is necessary to have a perfect connection between it and the surface to be deposited on.

## CHAP. IX.

## ON THE VARIOUS ARRANGEMENTS OF ELECTRO-METALLURGICAL APPARATUS.

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262. THE sources of electrical power which have been made available in electro-metallurgy, namely, the voltaic battery and magneto-electrical machine, have been already fully discussed in their general nature; particular modifications of the apparatus, the various forms in which they may be applied under different circumstances, and the conditions to be observed, form the subjects of the present chapter.

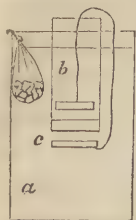
263. All electro-metallurgical arrangements, in which voltaic electricity is the source of power, resolve themselves into two classes; one in which the surface, receiving the deposit, constitutes part of voltaic apparatus, by which the electrical power is generated; and the other, in which the voltaic power is obtained from a battery, of which the surface, receiving the deposit, forms no part. The former is called the single-cell process, and the latter, the battery process.

264. The single-cell process which was the only one used in the early practice of the art, consists of an apparatus resembling, in the number and disposition of its parts, a Daniell's battery; the surface corresponding to the copper in that battery, being the surface or mould on which the deposition is to take place. This form of apparatus is still much used for the production of copies of coins, medals, plates, &c.



It is represented in *fig. 19.* *a* is a glass or earthen vessel,

*Fig. 19.*

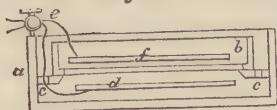


containing a saturated solution of sulphate of copper: *b* is a cylinder of glass, the bottom of which is closed by brown paper, plaster of Paris, or bladder; this vessel contains a solution of sulphate of soda, or muriate of ammonia (sal ammoniac), or chloride of sodium (common salt): *c* represents the plate or mould on which the deposit of metallic copper is to

be received; a wire, fixed by soldering or otherwise to this mould, is connected with a piece of zinc placed in the saline solution in the glass cylinder *b*. To set this apparatus in action, the outer vessel is filled with the cupreous solution, and some crystals of sulphate of copper, to keep the solution saturated, are suspended in the upper part of the vessel, either on a perforated metallic shelf, or in a piece of muslin, as the decomposition of the salt is continually going on during the working of the apparatus; the saline solution being put into the glass cylinder in which the zinc is situated, completes the preparation. If the metallic communication between the zinc and the mould be perfect, action immediately commences; the mould becomes almost instantly covered with a stratum of copper, which goes on increasing in thickness so long as the strength of the cupreous solution is maintained. The rapidity of the deposition is determined by the nature of the porous material with which the bottom of the glass cylinder is closed. If it is of brown paper, the deposition proceeds with considerable rapidity; bladder occasions a slower deposition; and plaster of Paris retards the process still more: the thickness of the various materials also influences the action, which is most intense when the interposed diaphragm is thinnest. From what has been said respecting Daniell's battery, the reader will easily understand the nature of the action, and the cause of the changes which take place in this apparatus.

265. *Fig. 20* represents an apparatus for manufacturing cop-

*Fig. 20.*



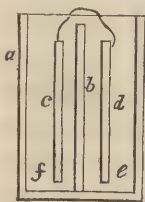
per plates, as described by Mr. Spencer:—*a* is a box, which may be made either of earthenware, wood, or glass, and of any size which may

be found convenient; *b* a box of either of the above materials, but having a thick brown paper, or thin unglazed earthenware bottom, the sides being impermeable by a liquid. This must be made to go into the interior of *a*, and to rest on the rim *c c*, running round the interior of the larger box, taking care, at the same time, that there shall be an inch or more of free space, according to the size of the apparatus, between the exterior of the small box and the interior sides of the larger one. The rim *c c* must be perforated with small holes, and it must be made to support a supply of crystals of sulphate of copper; *d*, the plate to be deposited on, to which a wire is attached, leading to the binding screw, *e*, fastened to the top of the exterior box; *f*, the plate of zinc, to which a wire is attached, also leading to the binding screw. The connection between the two plates is thus rendered perfect, and either may be conveniently removed without disturbing the other. A few projecting studs of wire on the sides of the interior box, are also found useful, to keep the zinc plate perfectly parallel, and to prevent it from touching the porous bottom. They must be varnished, to prevent local action; or, if the vessel be made of earthenware, they may be attached to the sides in the first instance, and be of the same material. The plate to be deposited on may be kept in its place by similar studs or moveable pieces of earthenware. "The ends of the wires must all be brightened before they are pressed together by the binding screws. When all is arranged, as shown in the figure, pour into the outer box a saturated solution of sulphate of copper until it is nearly full, and then pour into the interior one, containing the zinc, a weak solution of sulphate of zinc. At this stage of the proceedings,

let a quantity of the undissolved crystals of sulphate of copper, be placed on the perforated rim. Should this be neglected for any length of time, a brown powder will be deposited on the plate instead of the pure metal. This substance is the protoxide of copper, and will always be precipitated when the liquid is not kept thoroughly saturated with sulphate of copper. In summer the deposition goes on much quicker than when the weather is cold, as heat very much facilitates chemical decomposition."

266. A very convenient form of apparatus is represented

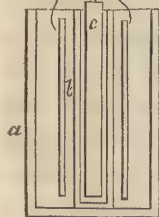
*Fig. 21.* in *fig. 21*. It consists of a trough *a*, made of porcelain, glass, or varnished wood. It is divided into two parts by a partition of unglazed earthenware or plaster of Paris, *b*. The zinc plate *c*, is placed in the compartment *f*, containing the dilute acid, or solution of muriate of ammonia to act upon it; and into the other compartment *e* is placed the saturated solution of sulphate of copper,



to which a little sulphuric acid has been added; crystals of the sulphate must be suspended in the upper part of the latter compartment, in order to maintain the saturation of the liquid. In this compartment the plate *d*, to receive the deposit is placed, and is connected to the zinc *c*, by a wire.

267. Another, and in some cases more convenient arrangement, is shown in *fig. 22*, where *a* is a cell of earthenware

*Fig. 22.* or water-tight wood, in the middle of which is placed a porous or unglazed earthenware cell *b*, the latter is filled with the dilute acid or saline solution, and contains the zinc plate *c*, and the former is filled with the acidulated cupreous solution; crystals being suspended in its upper part, as in all other modifications of this apparatus. In the outer vessel *a*, the plates to



receive the coating of copper are situated. The peculiarity in this apparatus is that two surfaces, each as large as the

zinc, can be experimented upon at the same time. The connection of the copper plates with the zinc is so evident from the figure that it needs no description. When dilute sulphuric acid is used in any of the instruments described, the zinc immersed in it must be amalgamated; but where solutions of muriate of ammonia or sulphate of soda are used, the amalgamation of the zinc is unnecessary.

268. Immediately after the publication of Mr. Spencer's paper, in which these forms of apparatus were first described, an important improvement was announced by Mr. Mason, by which a great economy is effected. Mr. Mason used an apparatus exactly similar to that of Mr. Spencer; but, instead of connecting together the zinc and the metal on which the deposit was to take place, he effected a communication through a second vessel, in which, by the passage of the voltaic current, a quantity of copper was precipitated, equal in amount to that precipitated in the primary cell. The process took somewhat longer time, but on the whole, was much more economical than any which preceded it.

269. In order to make this improvement intelligible, a

Fig. 23.

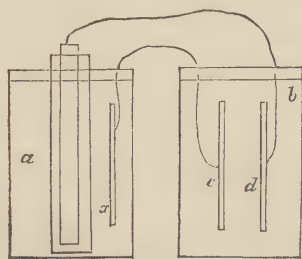


figure (*fig. 23*) is subjoined:—*a* is the common single-cell apparatus; the wire from the zinc, instead of communicating directly with the mould, is conducted into the vessel *b*, and is joined to the mould *d*; the mould *x* in the primary cell is connected with a piece of copper *c* in the cell *b*.

Now, the current of electricity, in passing through this arrangement, causes the deposition of copper to take place upon the moulds, *x* and *d*; but in order that the *modus operandi* of this instrument may be more clear, we shall again refer to the voltaic battery, and examine the nature of the chemical action of that instrument.



270.—Let us imagine, then, that we have, in the following experiments, a battery of sufficient power to decompose water. If the terminal wires of this battery, which we will suppose to be made of the metal platinum, be introduced into acidulated water, we shall observe gas escape from them, and by examination, we further find that the water is decomposed, and that oxygen is evolved at one wire, and hydrogen at the other. If the experiment be varied by the introduction of a solution of sulphate of copper into the acidulated water, a remarkable change in the products of the decomposition will take place. We shall now find that only one wire evolves gas, and that that gas is oxygen. On examining the other wire, where the hydrogen was evolved, we shall observe it to be covered with metallic copper: by continuing the experiment, the precipitated metal will gradually accumulate, the solution, will become paler, and at length colourless. When this happens, the whole of the copper will have been precipitated, and hydrogen will be again evolved from the surface of the newly-deposited metal. We see, then, that by passing a voltaic current through a metallic solution, the hydrogen evolved by the decomposition of the water, effects the reduction of the metal; it combines with the oxygen of the metallic oxide, thereby forming water, while the metal with which it was united is deposited, and attaches itself to the surface at which the hydrogen escaped; the acid which was combined with the oxide to form the salt, remains in solution (75.)

271. We will now consider what takes place when the wire or surface from which the oxygen is evolved is made of a metal that combines readily with oxygen—we will suppose copper. We shall observe that the hydrogen is evolved as usual, but that, in the place of oxygen, a brown powder will accumulate about the wire; the latter rapidly diminishes in size, and, by continuing the experiment a sufficient length of time, the whole of that part which was immersed in the water will disappear, and the action of the battery, through

the interruption of the circuit, will cease. The brown powder which appears is oxide of copper, and is formed by the combination of the oxygen with the copper of the electrode.

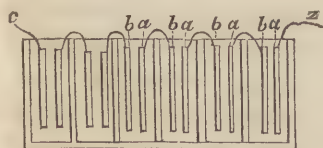
272. We will next suppose that we immerse two copper wires, or plates, connected with a voltaic battery, in a solution of sulphate of copper. We have already seen that a plate from which hydrogen is evolved, receives a deposit of copper when immersed in such a solution ; and we have also seen that a copper wire, or plate, when oxygen is evolved, combines with that element, forming oxide of copper. Now, as the oxygen evolved at one of the wires is chemically equivalent to the hydrogen liberated at the other, the quantity of oxide of copper formed by the combination of the oxygen with the copper of the former electrode, is exactly equal to that decomposed by the hydrogen at the latter ; hence, in the experiment under consideration, there is no visible evolution of gas at either of the wires, the only effect produced being the formation of oxide of copper at one of them, and its reduction on the other, and consequently, the transfer of metallic copper from one wire to the other. We will now observe these changes as they take place in the apparatus of Mr. Mason. We may suppose that the voltaic current originates at the surface of the zinc, and determines the formation of oxide of that metal ; passing to the second cell, it is accompanied by the evolution of hydrogen at the plate, *d*, and metal is deposited thereon ; the current, travelling through the liquid to the second plate, *c*, develops oxygen, which, combining with the copper, forms oxide ; passing from this cell to the first, it again occasions the evolution of hydrogen, and a second deposition of metal is effected on *x* ; the current completes its course by passing again to the zinc. In this arrangement of the electrotype apparatus, a double quantity of the reduced metal is obtained.

273. It is necessary to explain what will otherwise appear a discrepancy. We have supposed the use of a compound

battery in our illustrative experiment, though the cell, which in Mr. Mason's apparatus generates the electricity, is but a single one. The following fact explains the cause of this difference:—It requires considerable intensity to decompose water, if platinum or gold electrodes or poles are used; and in such a case the elements of the water are delivered in a pure form; but where the arrangements are such that the elements enter into combination before assuming the gaseous form, the intensity required for that decomposition is less; the intensity of the current seems to be augmented by the affinity between the oxygen and hydrogen, and the elements with which they are combining. We have seen that a single voltaic pair will determine a current through a solution of sulphate of copper, if the electrodes are of copper, though a series is required to decompose water with platinum electrodes; in the former case the evolved elements enter into combination, in the latter they do not.

274. It will immediately occur to the reader that if, by the voltaic current entering the solution in the second cell, copper is reduced, and by its passage from that cell, an equal amount of that metal is taken into the solution, by causing it to pass through a series of such cells, a similar quantity of copper will be reduced in each; such is exactly the case; and it is now common to cause the completion of the voltaic circuit to take place through six, or even more of such cells, and thus obtain, at a given expense of zinc, six times the quantity of copper that would be obtained by the single-cell apparatus. The process goes on much more slowly than if a single decomposition were being effected; but the great sav-

Fig 24.



ing in the consumption of material is more than sufficient to warrant the adoption of this plan. This arrangement is shown in *fig. 24*, where *a a* are the moulds on which the deposit

is to take place, and *b b*, pieces of copper to be dissolved. It is necessary to place the mould and copper plate very near each other, and parallel, as represented in the figure; and they should be as nearly of a size as may be.

275. The cell *a*, in Mr. Mason's apparatus, is, strictly speaking, a voltaic battery, and, although it *may* be used, as represented in the sketch, as an electrotype apparatus, by its negative plate being a mould on which a deposit of copper is to be effected; yet by far the most convenient plan, and, perhaps, even the most economical one, is to substitute for the cell *a*, in the arrangement represented, an ordinary voltaic battery; indeed, the apparatus now used for electro-metallurgical purposes, to the exclusion of almost every other, is that now recommended. The improvement introduced by Mr. Mason possesses such advantages, that the single-cell apparatus described by Mr. Spencer has already fallen into very general disuse. By generating the voltaic electricity in an apparatus distinct from that in which the precipitation of the metal takes place, a much greater command over the process is obtained, and the flow of electricity can be regulated with much greater nicety than when the mould to be deposited upon constitutes one of the elements of the battery. It is evident, too, that as the solution in the second, or decomposing cell, is always of the same degree of concentration, the experiment, when once adjusted, may be suffered to proceed, without risk of failure from any change in the nature of the solution. Another convenience attending this mode of procedure is its simplicity. In the single-cell apparatus, the solution of sulphate of copper is suffering continual loss of the salt, owing to its decomposition, and it is necessary to replenish the solution by the suspension of crystals of sulphate of copper in the upper part of the vessel; but in Mr. Mason's apparatus it is only necessary to use so much sulphate of copper as is sufficient to form the original solutions; for, as has been shown, the solution is not at all



affected by use, and is in precisely the same state of concentration throughout the longest process in which it may be employed.

276. The nature of the apparatus best suited for depositing metals, depends on the metal to be deposited, and the extent to which the process is to be carried on. For small operations, the single-cell apparatus answers very well; and deposits, of copper, silver, and gold, may be very readily effected by such an apparatus, where the surface to be deposited on is of small extent. For gilding coins, and such like articles, one of the two compartments formed by the porous diaphragm, (*b*, *fig. 21*) should be filled with the solution of chloride, sulphite, or cyanide of gold, and the other with a very dilute acid, or if the coin or medal be very small, with pure water only. The coin or medal is connected by a wire with a piece of zinc; the former is immersed in the auriferous solution, and the latter in the dilute acid or water.

277. The gilding of very small articles may be effected without the use of any other means than the solution of gold and a small piece of zinc. Small coins may be gilded in this way, by being laid in a shallow vessel containing the gold solution, and touched with a slip of zinc; the zinc, liquid, and metal of the coin, form a voltaic combination (48), by virtue of which, the gold will be deposited on the coin. In the same way, the interior of small vessels, bowls of spoons, watch cases, and other articles may be gilt: the solution of gold may be poured into the vessel, and the slip of zinc touched against the edge of the vessel, and also partially immersed in the solution. The zinc must be moved about in order to equalize the deposit, as the latter is always formed in greatest quantity in the vicinity of the zinc. The distance to which the slip of zinc is immersed, is of importance; if too much zinc surface be exposed to the solution, the surface of the article under experiment will be coated with minute bubbles of hydrogen, and the gold will be deposited in the

form of a black powder; the remedy in such a case is obvious. This process is only recommended to be used in those cases where very small articles are to be coated, and where the number of them is so limited as not to warrant the charging of a battery; the immersion of the zinc occasions much precipitation of the metal by local action (81), and hence the process is not economical.

278. The single-cell process may be used for the production of deposits of copper, as in making impressions of coins, medals, and engraved plates; and it may also be used for making similar deposits of gold and silver. The following circumstances must be attended to in using this form of apparatus:—The strength of the solution being constantly diminished by the reduction of the salt, it is necessary to replenish the solution by the addition, from time to time, of fresh quantities of the salt; or the same effect may be produced by keeping a quantity of the salt in the upper part of the vessel, as represented in *fig. 19*.

279. In using the single-cell apparatus for coating articles on all sides with a film of metal, as in silvering and gilding, it is necessary to turn the articles from time to time, in order to present every part in its turn to the porous diaphragm, (*b, fig. 21*), as the deposition goes on with much greater rapidity on the side turned towards the diaphragm, than on the opposite side; and if this precaution be neglected, the film of metal will not be of uniform thickness.

280. Where the film of metal deposited is very thin, as in plating with gold and silver, the form of apparatus represented in *figs. 21 and 22* may be employed; but when the deposit is of considerable thickness, as in copying engraved plates, the position of the matrix or mould becomes highly important. If it is placed vertically, the deposited metal will possess various degrees of hardness, from the different degrees of concentration of the upper and lower parts of the cupreous solution. The circumstances which determine the

quality of the deposited metal, are explained in a succeeding chapter ; but we will anticipate that part of our subject by observing, that the metal may have an extreme hardness,—may be so crystalline as to break with the slightest touch, or be almost as soft as lead, and may assume every variety of texture between these extremes ; and as these various characters are produced principally by the relation between the current of electricity and the concentration of the solution, the reader will appreciate the importance of attention to the position of the mould.

281. When the mould is vertical, the solution in contact with the bottom of it, losing a portion of its saline matter, becomes specifically lighter than the surrounding solution, and is, consequently, buoyed up ; and as the same action is taking place at every part of the plate, an upward current is established on its surface ; this current is of course greatest at the upper part, and it loses more and more of the cupreous salt as it approaches the top ; this gives rise to a difference in the texture of the copper in different parts of the deposited plate.

282. Where a considerable thickness of metal is deposited in this way, the plate will exhibit a number of grooves on its surface, formed by this ascending current ; the lighter liquid having found the most favourable channels, continues to flow therein, and, from the small amount of the salt contained in it, very little deposit accumulates there ; while the intermediate portions being exposed to the more concentrated solution, the deposition goes on at those parts with facility ; hence, the grooved appearance of the surface.

283. These inconveniences may in some degree be remedied by inclining the plate, so that the currents may rise through the liquid without passing over its surface ; but with large plates, it is much more convenient to lay them in a horizontal position. In this case, it is necessary to place the mould or plate to be deposited on, at the bottom of the vessel, and the

copper-plate to be dissolved, over it ; the precaution of introducing a piece of muslin, or some such fabric between them, must not be omitted, otherwise the impurities with which the copper to be dissolved is contaminated, will fall down as the pure metal is taken into the solution, and, lodging upon the mould, will at first impair its delicacy, and afterwards its solidity.

284. The reader may, perhaps, suppose that this objection would be obviated by reversing the position of the mould ; that is, by placing it in the upper part of the vessel, face downwards, and the plate to be dissolved, under it. This plan is attended with so many inconveniences that it cannot be practised advantageously. There is, first, the liability of minute portions of air being retained in the intricate parts of the mould or surface, and from which, in its inverted position, it is scarcely possible to free it ; and there is a still more weighty objection in the circumstance, that there is a greater irregularity in the state of the solution with this arrangement than with any other. The stratum in contact with the inverted mould, when deprived of a portion of its salt, being lighter than that immediately below it, has no tendency to give place to the more concentrated solution : when, however, this dilute stratum has accumulated a little, it escapes at the edges of the horizontal plate ; and, by another portion becoming exposed to action, the process for a time continues to go on well. It is only, however, until the whole of the solution *above* the plate is thus deprived of its cupreous salt ; there is then no tendency to circulation ; the lighter fluid is in the upper part of the vessel, and the heavier at the bottom ; the action becomes impeded, and the small quantity of copper deposited from such a dilute solution is of such a texture as to render it perfectly useless. The copper dissolved from the waste plate at the bottom of the vessel will crystallize there, while the upper part of the same solution is exceedingly dilute. These difficulties would not present themselves



if a constant agitation of the liquid could be kept up; but this is obviously impracticable. The most convenient arrangement, then, is that in which the mould or plate to be deposited upon is at the bottom of the vessel, and the piece of waste copper to be dissolved above; in this case, as the solution is deprived of its salt of copper, it rises and gives place to a more concentrated portion, while the salt formed by the solution of the waste copper descends to the lower part of the vessel; and with such an arrangement, the process goes on with much regularity.

285. The reader must particularly bear in mind that, in whatever position he may place the surface to receive the deposit, the piece of metal forming the positive pole must be parallel to it; if this condition is not observed, the deposit will be of different thicknesses at different parts; if the two surfaces are inclined to each other, a much greater thickness will be observed at the point where the two surfaces are nearest; and in proportion as they become more distant from each other, will the thickness of the deposit diminish.

286 In precipitating metal upon very irregular surfaces, it is difficult to obtain a deposit of uniform thickness; in such a case, it is desirable to bend the positive plate so as to assume the general figure of the negative surface; and when a sufficient thickness of metal has accumulated on those parts nearest the positive pole, the deposit may be removed from the solution, and they may be varnished or covered with some non-conducting substance, such as wax; on again introducing the surface thus treated, the copper will only be precipitated on the more distant or unvarnished parts; if the amount of surface thus defended from the solution is considerable, a difference in the texture of the metal will be produced, unless such alterations are made in the arrangement of the apparatus as will be hereafter pointed out, when treating of the conditions on which the nature of the deposit depends.

287. These observations relative to the proper position to be observed between the surface deposited on and the opposed metallic plate, are equally applicable to the single-cell and battery processes. For thin deposits, as in gilding and silvering, the position of the articles is of little consequence; they are generally suspended vertically in the solutions.

288. For all precipitations on a large scale, the most convenient arrangement is that of a large vat for containing the metallic solution, to two opposite edges of which strips of metal are attached, for the purpose of making connection with the battery, or other source of electrical power. One of these strips is connected with the zinc end of the battery, and the other with the copper or silver end. In order to suspend the articles to be coated in the solution, and at the same time connect them with the zinc end of the battery, metallic rods should be laid across the vat, one end of each of such rods resting on the strip of metal connected with the zinc end of the battery, and the other resting on, but insulated from, the strip connected with the copper or silver end of the battery. In order to thus insulate it, a strip of wood, or even two or three folds of paper, may be introduced between it and the metal. The articles to be coated may be suspended from these rods by copper wires.

289. The plates of metal to be dissolved are connected to the copper or silver end of the battery by being similarly suspended by wires from metallic rods, one of each of which rests on the edge of the vat, connected with the copper or silver end of the battery, but insulated from the zinc end, in the manner already described. In this way, a great number of rods may be laid across the vat, from every alternate one of which, several articles may be suspended, while the intermediate rods support the plates to be dissolved. Vats are commonly used in manufactories of such a size as to admit of the introduction of eighteen or twenty dozen of spoons.

290. It is scarcely necessary to remind the reader that all

these metallic surfaces, by which connection is made with the battery, must be kept perfectly clean, by frequent rubbing with sand paper, or by other means; if this precaution be neglected, the passage of the current will be obstructed, and imperfect results obtained.

291. The nature of the vessels for holding the solution, from which the metals are to be precipitated, merits the attention of the electro-metallurgist. Where the operations are on a small scale, no material can be compared with glass; next to that, stoneware should be selected, or well-glazed earthenware. In selecting vessels of earthenware, the greatest attention must be given to the nature of the glaze used in its manufacture, as the glaze of the greater part of such vessels is attacked by acid and saline solutions, and in a short time they become perfectly useless, the penetration of the solution completely disintegrating them.

292. Vessels of lead have been recommended, and may be used in those cases where the nature of the solution used will admit of it; but as that metal is attacked by many of the solutions employed by the electro-metallurgist, its use is very limited. Vats made of wood, and well varnished by resinous matters, have been frequently used, but these are by no means universally applicable, as they are acted on by some solutions; for example, shell lac, or sealing wax, is almost immediately rendered soft and useless by the solution of cyanide of silver.

293. The vessels now commonly used in large establishments are constructed as follows:—Two wooden vessels are made of such sizes, that one nearly fits inside the other, a space of about a quarter of an inch being left between them on every side; into this space, melted pitch is poured, so as to fill it completely: a vessel is thus formed which is perfectly impervious to liquids, and which answers admirably for electro-metallurgical purposes.

294. It is not necessary to have a separate solution for each

article, or series of articles, operated on; that is to say, any number of articles connected with different batteries may be at work in the same vat, without the action of one affecting that of the other. It is, however, better to connect all the power of the batteries employed, with the whole of the articles operated on, by means of the contrivance already described (288), rather than confine a small power to a small series of articles; the larger the scale on which operations are conducted, the more uniform will be the results.



## CHAP. X.

ON THE CIRCUMSTANCES WHICH INFLUENCE THE  
QUALITY AND QUANTITY OF ELECTRO-METALLUR-  
GICAL DEPOSITES.

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295. It was observed, by the earliest experimenters in electro-metallurgy, that the character of the deposited metal was affected by the rapidity with which it was precipitated (16), and by various other causes; and more recent investigations have determined with accuracy, the conditions on which the production of the various kinds of metallic deposits, depend.

296. Metals may be deposited in the form of a dark powder, without cohesion, and having a non-metallic appearance; or in continuous layers, as ductile and malleable as the same metals can be produced by the common methods of reduction; as distinct crystals, or as a mass, composed of crystalline grains, having little cohesion.

297. The cause of these differences in the character of the deposited metal, is by no means well understood, although the conditions under which they are produced are well known.

298. The circumstances which operate to produce the different kinds of deposits, are the quantity and intensity (58) of the electric current; the relative size of the surface receiving the deposit, and that suffering solution; the distance of these surfaces apart; the strength of the solution; the conducting power of the salt under decomposition; and the temperature of the battery and solution.

299. If the quantity (58) of the current be too great for the surface to be deposited on, the metal will be precipitated as a black powder, having no cohesion, and presenting none of the appearances of a metal; and the same effect will be produced if the intensity of the current be too great; if, on the other hand, the quantity and intensity of the current be too small, the metal will be reduced in a crystalline form.

300. If the size of the plate, or electrode, in connection with the copper or silver end of the battery, be too large, compared with the surface receiving the deposit, the metal will be reduced in the form of a black powder; if it be too small, a crystalline deposit will be the result.

301. The distance between the plate, or electrode, in connection with the copper or silver end of the battery, and the surface on which the metal is reduced, has an important influence on the nature of the deposit; if the plate is too near, a black powder will be thrown down, (supposing the battery to be sufficiently powerful); when removed to a greater distance, the ductile metal will be reduced; and when still further removed, a crystalline deposit will be formed.

302. The strength of the metallic solution has a most important influence on the character of the deposit; with a strong solution, there is a disposition to the production of the crystalline metal; by dilution, the metal becomes more ductile; and by very large dilution, a black powder will be precipitated.

303. The character of the deposit produced by the same voltaic power, differs with different salts of the same metal. The facility with which different salts suffer decomposition in the voltaic current, determines the character of the deposit which will be produced from them with the same voltaic power. Thus, the battery which will produce a crystalline deposit with a saturated solution of sulphate of copper, gives a ductile metal with a saturated solution of the nitrate of copper; and similarly with salts of the other metals.

304. The temperature of the solution in the precipitating vessel, as well as that of the battery, must be constant, in order to produce uniform results, for the application of heat increases the conducting power of the solution under decomposition, as well as the activity of the battery, both of which causes determine the circulation of a more copious current; the former, by diminishing the opposition to its passage, and the latter, by exalting the affinity by which the current in the battery is determined. For example, the current from a single cell of the acid battery, transmitted through a saturated solution of sulphate of copper, by means of copper electrodes of the same size as the plates of the battery, gives a small deposit of crystalline metal, at a temperature of 60° F.; but when both the battery and decomposition cell are heated to a temperature of 180° F., a copious deposit of ductile metal is produced.

305. The whole of the circumstances which interfere with the character of the deposited metal, resolve themselves into two; namely, the quantity of electricity circulating through the apparatus, in relation to the size of the surface receiving the deposit; and the conducting power of the solution.

306. The intensity of the current (58) operates only by effecting a change in its quantity, for however large a quantity of electricity the battery employed may be capable of producing, if the current have not an intensity sufficient to effect the decomposition of the solution (58), it will be obstructed; by increasing its intensity, the current may be made to pass in small quantity, and thus produce a certain kind of deposit; and by still further increasing the intensity, the resistance to the passage of the current is so far overcome, that a very large quantity passes. In this way the intensity of the current determines the quantity of electricity which will pass in a given time through any solution.

307. The difference in the size of the electrode, or surface receiving the deposit, and that suffering solution, only affects

he character of the deposit, by determining the quantity of electricity passing. If two electrodes be immersed in a saline solution, and connected with the extremities of a battery, in the circuit of which a galvanometer (122) is included, the needle will show, by its greater deflection, that a more copious current passes when both the electrodes are wholly immersed, than when one of them is partially removed.

308. A greater or less distance between the electrodes also determines a change in the quantity of electricity passing. Two electrodes, immersed in a saline solution, and connected with a battery having a galvanometer (122) in its circuit, determine a much more copious current when near each other, than when at a distance, as the deflection of the galvanometer needle will demonstrate.

309. The conducting power of the solution is affected by the quantity of metallic salt contained in it, and the temperature at which it is maintained. It has already been stated (302) that with a saturated solution of a metallic salt, there is a tendency to the production of the crystalline deposit—that moderate dilution determines the production of a ductile metal; while very copious dilution produces a black powder. These effects are precisely analogous to those which present themselves when the conducting power is altered, without altering the strength of the solution. Thus, with a saturated solution of sulphate of copper, a crystalline deposit is produced by a single cell of the acid battery; but if, by the elevation of temperature, or the introduction of acid into the solution, its conducting power be increased, the character of the deposit will change; a ductile metal will be thrown down. Now, precisely the same effects present themselves when the saturated solution is diluted; that is to say, the deposit assumes that character which usually accompanies an increased conducting power in the solution. We may, therefore, consider the conducting power of any metallic solution to be impaired, in proportion as the



quantity of metallic salt in the solution is increased; for the result of such addition is the production of a deposit resembling that produced by diminished conducting power.

310. The real cause of this apparent diminution of conducting power, by increasing the strength of the solution, is very obvious. With a saturated solution of a salt, the electric current, in its passage between the two electrodes, is conducted by so great a number of the atoms of the salt, that the quantity of the current, compared with the quantity of the salt, is small; while in a dilute solution, (the battery, electrodes, and all other circumstances being equal,) the current is conducted by so small a number of the atoms of the salt, that its quantity, compared with the quantity of the salt, is large. Hence, a current in a strong solution is virtually small, while the same current in a weak solution is virtually large; and thus it is, that with a strong solution, effects similar to those produced by inferior conducting power, are presented; while in a weaker solution, effects are produced similar to those produced by superior conducting power.

311. The application of heat is another method of increasing the conducting power of a solution, and changing the character of the deposit. In heating a solution, a greater quantity of electricity passes, the quantity of the salt remaining the same; in diluting a solution, the quantity of electricity remains the same, but the quantity of the salt is relatively diminished.

312. The production of the metallic deposit in the form of a black powder (296), is usually accompanied by the evolution of hydrogen, and is probably occasioned by the reduction of the metallic salt by that element. Although it is impossible, in the present state of electrical science, to determine with certainty whether the reduction of metals in the voltaic circuit is a primary or secondary effect (74); yet there is strong reason to believe that a metallic salt may be decomposed primarily, being resolved into the metal and its

associated radical (41); and there is demonstrative evidence that the decomposition may be a secondary effect (72), for hydrogen decomposes many metallic salts. It may, therefore, be assumed, that the production of the crystalline and ductile deposits are produced by the primary action of the current, unaccompanied by any decomposition of the water in which the salt is dissolved; and that the production of black metallic powder is the result of the decomposition of the water, in addition to that of the metallic salt. Various considerations favour this view; it is easy to conceive that a metal may assume a crystalline form, when liberated from a solution so slowly as to allow of the full operation of the molecular attraction, by which crystalline form is produced; and it is also easy to conceive that when the metal is deposited so rapidly as not to admit of this arranging of the particles, that a ductile metal is produced; and where, in addition to this deposition of metal, there is a liberation of gaseous hydrogen, the effect produced by the interposition of the latter between the particles of the former, is the prevention of that intimate relation between the particles, which is necessary to cohesion.

313. When the electro-metallurgist wishes to make any change in the character of a deposit, the means to be taken are obvious. If a black powder is produced, and it is wished to obtain a ductile metal, the size of the battery must be diminished, or its intensity reduced by diminishing the number of the series; or the size of the plate suffering solution may be reduced, or its distance from the article receiving the deposit increased; or the temperature of the solution may be depressed, or its strength increased; the alteration in the size or intensity of the battery is, however, the most convenient plan, and the only one which can, in general, be adopted.

314. If a crystalline metal is deposited, and a ductile metal is desired, the quantity or intensity of the electric current must be augmented, by increasing, in the former case,

the size of the battery, and in the latter, the number of the series; or the conducting power of the solution may be improved by dilution, or the addition of acid, when the latter is compatible with the salt; by increasing the size of the plate, or electrode, suffering solution, or by bringing it closer to the surface receiving the deposit; by heating the solution, or by diluting it; in this, however, as in the former case, the alteration in the character of the deposit can only be conveniently effected by making the necessary alteration in the battery.

315. In order to produce a black powder from a solution giving a ductile metal, the quantity or intensity of the current must be increased; or the plate undergoing solution, enlarged, or brought nearer the surface receiving the deposit; or the solution may be heated, or its conducting power improved by the addition of acid. The necessary change may be most conveniently effected by increasing the quantity or intensity of the current; or the addition of acid, when the latter is not incompatible with the salt under experiment.

316. To produce a crystalline deposit, the current must be diminished in quantity or intensity, or the conducting power of the solution reduced, either by diminution of temperature, or the addition of an extra quantity of the salt. The most convenient means of producing the crystalline deposit, is the use of a strong or saturated solution of the salt.

317. In producing the various kinds of deposits with the magneto-electrical machine, the same relations, between the current and the state of the solution, as pointed out with reference to the battery, must be observed; the quantity of the magneto-electric current may be regulated in the way already pointed out (149).

318. The production of these different kinds of deposits has been referred to the evolution of hydrogen, in the case of the black powder, and the want of a tendency to its evolution in the case of a crystalline deposit; and when the arrange-

ment is such that a small additional intensity or quantity would devolope the black powder, the ductile metal is produced. As the evolution of hydrogen at the negative plate, or its absence there, depends entirely on the condition of the battery and decomposition cell, a reference to its production is only another way of expressing the condition of the apparatus.

319. The following table exhibits the results of a number of experiments, made for the purpose of exhibiting the effect of different relations between the size of the battery, the character of the solution, and the size of the electrodes. The battery employed consists of two plates of amalgamated zinc, between which is placed a plate of silver of the same size ; the distance of the silver from each zinc plate is half an inch ; the electrodes in every experiment were  $1\frac{1}{2}$  inches distant from each other, and the average temperature  $60^{\circ}$  F.



## 320. BATTERY CHARGED WITH ONE PART OF CONCENTRATED ACID TO EIGHT OF WATER.

No.	Solution Employed.	Size of electrodes compared with each other.	Size of electrodes, (the largest where there is a difference) compared with negative metal of battery.	RESULTS.
1	Concentrated solution of sulphate of copper.	equal.	twice the size.	Distinct, detached, hard, crystalline grains, dull red colour.
2	Ditto	positive half of negative.	equal.	Distinct hard crystals, red colour, small in quantity.
3	Ditto	equal.	equal.	Clusters of hard, compact, crystals, brilliant red colour, small quantity.
4	Ditto	equal.	half the size.	Compact crystals, so thickly clustered, as to form a continuous stratum,—light red colour, larger in quantity than above.
5	Concentrated solution of sulphate of copper and one twentieth of sulphuric acid.	equal.	twice the size.	Continuous stratum of fine crystalline structure, clay red colour, having so little cohesion as to break on attempting to bend it.
6	Ditto.	positive half of negative.	equal.	Continuous stratum, brittle crystalline on surface, rather lighter colour than No. 6.
7	Ditto.	equal.	equal.	Continuous stratum, slightly ductile, fine crystalline surface, bright red colour.
8	Ditto.	equal.	half the size.	Continuous stratum, ductile, rather hard, very fine crystalline surface, bright red colour.
9	Ditto.	negative half of positive.	equal.	Continuous stratum, ductile, rather hard, fine crystalline surface, red colour.
10	Concentrated solution of sulphate of copper with one third diluted sulphuric acid.*	equal.	twice the size.	Continuous stratum, deficient in cohesion, crystalline surface, slightly ductile, rather hard, bright red colour.
11	Ditto.	positive half of negative.	equal.	Continuous stratum, ductile, fine crystalline surface, bright red colour.
12	Ditto.	equal.	equal.	Continuous stratum, ductile, rather hard, fine crystalline surface, bright red colour.
13	Ditto.	equal.	half the size.	Continuous stratum, not very ductile, very fine crystalline surface.
14	Ditto.	negative half of positive.	equal.	Continuous stratum, ductile, rather hard, fine crystalline surface, large in quantity.

\* Consisting of one part by measure of acid, and eight of water.

321. By an examination of this table, the reader will observe that, when the solution was neutral, and a large surface of electrodes exposed, the formation of distinct crystals was the result; that as the size of the electrodes was diminished, and their proportions made such as to determine a more copious current, the character of the deposit changed; and through the whole table a gradual improvement in the character of the copper may be traced, as the circumstances which obstruct the passage of the current are removed. These circumstances, it is hardly necessary to remark, are the character of the solution, and the varying size of the electrodes.

322. The above table might have been continued to a much greater extent, but such extension would have been comparatively useless; the above shows what proportion must be avoided when the crystalline deposit is not wanted; and the reader will discover from it, that in order to obtain a good ductile metal from the solutions given, he must cause a more copious flow of electricity than is afforded by any of the arrangements there described, by increasing the size of the battery, or diminishing the size of the electrodes.

323. The following tables show the result of experiments made by a commission of members of the Academy of Sciences of Paris. They exhibit the influence of temperature in increasing the conducting power of a metallic solution, and, consequently, the quantity of metal deposited in a given time; they also demonstrate that the quantity of metal deposited is (all the circumstances remaining the same,) equal in equal times. In manufacturing operations, however, where the battery is employed, it is impossible to preserve that uniformity, in the various influencing circumstances, which is necessary to give such uniform results; and hence the length of time during which the articles are under operation, is not an accurate measure of the metal deposited; but with the magneto-electrical machine, the time and quantity of deposited metal are, as already stated (153), in a sufficiently accurate relation, even for large manufacturing purposes.

324. In the following experiments, a solution was employed, consisting of one part by weight of cyanide of gold, dissolved in one hundred parts of water.

325. TEMPERATURE OF THE SOLUTION, 60° F.

				Gold deposited, GR.
First immersion of two minutes	.	.	.	0.009
Second ditto ditto	.	.	.	0.013
Third ditto ditto	.	.	.	0.014
Fourth ditto ditto	.	.	.	0.014
Fifth ditto ditto	.	.	.	0.013
Mean				0.0126

326. TEMPERATURE OF THE SOLUTION, 95° F.

First immersion of two minutes	.	.	.	0.028
Second ditto ditto	.	.	.	0.028
Third ditto ditto	.	.	.	0.030
Fourth ditto ditto	.	.	.	0.029
Fifth ditto ditto	.	.	.	0.027
Mean				0.0284

327. TEMPERATURE OF THE SOLUTION, 140° F.

First immersion of two minutes	.	.	.	0.063
Second ditto ditto	.	.	.	0.063
Third ditto ditto	.	.	.	0.063
Fourth ditto ditto	.	.	.	0.063
Fifth ditto ditto	.	.	.	0.063
Mean				0.063

## CHAP. XI.

## ON ELECTRO GILDING, PLATING, &amp;c., AND THE PRODUCTION OF WORKS OF ART BY ELECTRO-METALLURGY.

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328. THE principles on which the reduction of metals by voltaic agency depends, have been treated of in the preceding chapters; the application of these principles to the processes of electro gilding, plating, coppering, &c., and the production of works of art by the agency of electricity, will be considered in detail in this chapter.

329. All electro-metallurgical processes admit of considerable variations in their details. The production of any required deposit, as already explained (322), may be brought about by adapting the strength and temperature of the solution to the quantity and intensity of the electric current; and any alteration in one of the circumstances, renders necessary a corresponding alteration in the others; hence it is that one operator employs and recommends a strong or saturated solution, and another dilute one. A solution of almost any strength may be employed to produce any required deposit, but in treating of the details of the various electro-metallurgical processes, the author will confine himself to those proportions between the strength of the solutions and the different parts of the apparatus, which are used successfully in manufactories, or which his own experiments have demonstrated to be effective.

330. In depositing films of gold, for the purpose of infilming or gilding articles, a solution of cyanide (174) or sulphite (178)



of gold should be employed, in preference to every other. The solution may be of the strength directed in chap. vi.

331. Where it is desired to work with great rapidity, a weak solution of gold, containing about one ounce of gold to two gallons of water heated to the boiling point, may be employed; such a solution, when the strength of the electric current is properly regulated, deposits with surprising rapidity.

332. The battery employed may be Daniell's (91), or the common acid battery (109); a single cell of Daniell's possesses sufficient intensity, but when the acid battery is employed, a series of at least two should be employed. When very rapid action is required, a series possessing greater intensity must be employed. The size of the battery used for gilding may be less than that used for the deposition of other metals; a Daniell's battery will work effectually when the surface to be gilt exceeds considerably that of the battery. The vessel containing the solution of gold should be of glass or earthenware; if of the latter substance, care must be taken to select one which is not attacked by the solution. The articles to be gilt must be attached to the zinc end of the battery, and a plate of gold to the copper or silver end, to maintain the strength of the solution. The exact size of the plate of gold to be dissolved, compared with that of the surface to receive the deposit, may be varied to a considerable extent without inconvenience; as it is increased, however, the size of the battery must be diminished, or some equivalent alteration in the arrangement of the apparatus effected (298). It is usual to employ a plate of gold, exposing about the same surface as the article to be coated. Its size may, however, be increased with decided advantage, and some manufacturers employ a surface two or three times the size of that to be gilt. The advantages of using so large a plate are the following:—By using a small surface, the quantity of gold dissolved does not equal that deposited, and hence the solution is continually deteriorating; the thickness of the coating of deposited gold

is irregular, when the surface exposed is small, as the current from the plate is almost wholly conducted by that part of the article opposed to it, and the reduction of metal is consequently greater there, than on the more distant parts. By using a large plate of gold in the solution, both these difficulties are avoided; the quantity of gold dissolved more nearly approaches that reduced, and the strength of the solution is more uniformly preserved; and the deposited metal is of more uniform thickness on all parts of the article. If a small plate be used, it will be necessary to turn the articles from time to time, in order to present all parts of their surfaces to the plate of gold in connection with the copper or silver end of the battery. In gilding on the large scale, the articles and plates of gold may be suspended in the precipitating vats, in alternate rows (288), and there is then no necessity for changing their position.

333. The surfaces to be gilt must be cleaned by one of the processes already described (230), and amalgamated by immersion in the solution of nitrate of mercury (236). If there is any oxide or scale on the articles, it must be removed previous to dipping, by immersion in dilute sulphuric acid, or, as it is commonly called, "pickle." The objects to be gilded must be connected with the zinc end of the battery, and the electrode, or plate of gold to be dissolved, with the copper or silver end. It is desirable to make all the necessary arrangements before introducing the articles into the precipitating vat, so that the electric current may be completed by their introduction; by pursuing such a course, the local action which occurs with many metals when immersed in the solution of gold, is, to a great extent, prevented.

334. The operator should be particularly careful to determine as copious a flow of electricity as possible, immediately on the immersion of the articles; it is found that such treatment, combined with the amalgamation with mercury, produces a degree of adhesion, between the deposit and the surface of

the article, which was believed impracticable in the early practice of the art. The flow of electricity may be such as to give a dark colour to the surface of the metal; this intensity need not be kept up long. The most convenient way of carrying this plan into effect, is to introduce each article, if large, or several, if small, into the solution at one time, taking care to direct the whole strength of the battery upon them; during the time they are under operation, another article, or series of articles, may be prepared, and the whole battery power may be directed upon them; and so on, until the whole have been thus treated, when they may all be connected, and the deposition made to proceed regularly.

335. It is necessary to examine the apparatus from time to time in order to ascertain that the deposition is going on properly; any alteration in the character of the metal may be effected by the means pointed out in the preceding chapter. It may be properly mentioned in this place, that when the character of the deposit renders it desirable to determine a greater flow of electricity, the conducting power of the solution of cyanide or sulphite of silver cannot be conveniently increased by the addition of acid (314), and the remedy must, therefore, be sought in an increased power in the battery; the conducting power may, indeed, be increased by the addition of cyanide of potassium to the cyanide, or sulphite of potassa to the sulphite of gold; but an alteration in the solution is not recommended.

336. In depositing gold, so as to produce copies of works of art, and where, in general a deposit of considerable thickness is required, the size and position of the electrode connected with the silver or copper end of the battery, require considerable attention. If the deposition is to be effected in the interior of the mould, the exterior must be defended from the action of the solution, and the electrode of gold must be in the form of a rod, suspended in the centre or axis of the mould, if the latter is nearly a regular figure; if it is other-

wise, the electrode should be of such a form as to be nearly equi-distant from every part. When a sufficient thickness of gold has been deposited, an inferior metal, such, for example, as copper, may be reduced in the interior, so as to strengthen it. The article must be removed to a proper solution of copper, and a copper electrode substituted for that of gold.

337. To produce a copy of any work of art by deposition on the exterior of a mould, it is necessary to proceed with great caution; and with the utmost attention, the result will be inferior to that produced by internal deposition. The plate of gold opposed to the mould, must surround it, as nearly as possible, in every part; this condition is indispensable to the production of a deposit of uniform thickness. In reducing metals upon very irregular surfaces, it is difficult to obtain a deposit of uniform thickness, even where the utmost care is used; in such cases it is desirable to bend the positive electrode, so as to give it the general figure of the mould; and when a sufficient thickness of metal has accumulated on those parts nearest the positive electrode, they may be defended from further action by removing the deposit from the solution, and varnishing them with caoutchouc, or some other non-conducting substance.

338. By referring to the table of equivalents (32) it will be observed that the combining proportion of gold is very high, and consequently the quantity of that metal liberated in the precipitating vat is much greater than that of the zinc dissolved in the battery; the proportions, theoretically, are 199.21 to 32.31; in practice, the difference will not be found so great, owing to local action (81) in the battery, which can never be wholly prevented. If a compound battery be used, 32.31 parts of zinc will be dissolved in every cell, for every 199.21 parts of gold deposited. It is owing to the high equivalent of gold, that a smaller battery may be used for depositing on a given extent of surface, than in depositing



most other metals (332); a fact which has been already pointed out.

339. The metals which may be conveniently gilded by electric agency are platinum, silver, copper, brass, and alloys of copper generally; steel, iron, and pewter, cannot be gilded satisfactorily, unless they be first coated with a thin film of copper.

340. Electro-plating is best effected by the use of the solutions of cyanide (185) or sulphite (187) of silver; the latter by preference. The articles to be plated must be properly cleaned (230), by scouring (233), or dipping (231), and if any oxide be on their surface, it must be removed by "pickling," previous to "dipping." The battery employed may be a single cell of the acid battery (109), or a Daniell's (91); the latter is to be preferred. If the simple acid battery be used, the zinc surface should be about equal to the surface to be plated, and the positive electrode should be a plate of silver, exposing a surface not less than that to be plated; it may be made double or treble that size with advantage (332). The remarks made on amalgamation, when treating of gold (333), and the direction of an intense current at the first immersion of the articles, apply in the case of silver. The articles must be connected with the zinc end of the battery; and the plate of silver to be dissolved, with the copper or silver end, and all the connections should be made before introducing the articles into the solution. When large numbers of small articles are to be operated upon, they and the plates of silver to be dissolved, may be hung in alternate rows, as already described (288). Any alteration may be made in the character of the deposit, by observing the directions given in chap. x. The remarks made relative to the production of works of art in gold (336), apply to their production in silver.

341. By consulting the table of equivalents, the combining proportion of silver will be found to be 108.3, that of zinc

being 32.31 ; consequently, 108.3 parts of silver will be deposited for every 32.31 parts of zinc dissolved in the battery, or, in case a compound battery be used, in each cell.

342. The metals which may be most conveniently plated with silver by means of electricity, are platinum, gold (should occasion ever require it), copper, brass, and the alloys of copper generally, pewter, iron, and steel. The alloy of nickel, called German silver, is, however, more extensively employed for electro-plating than any other metal or alloy, and the admirable results produced with it, warrant the preference it has obtained.

343. Platinum may be precipitated from either of the solutions before enumerated (198), but the chloride is the only salt which is commonly used. Considerable care is requisite in the deposition of this metal in the ductile state. In order to produce the ductile metal, a very feeble current must be employed, and the positive electrode should be very small. The solution must be neutral, as it is almost impossible to produce a ductile deposit from an acid solution of this metal. In order to ensure its perfect neutrality, it is advisable to add soda to the solution, and thus form the chloride of platinum and sodium. When it is desired to precipitate the platinum in the form of a black powder, as in making the platinized silver of Smee's battery, and platinized platinum for the electrodes of voltameters (121), the solution may be acid, and the current of electricity may be both large in quantity, and of considerable intensity ; there is no difficulty in producing this kind of deposit.

344. The equivalent of platinum is 98.84 ; and, consequently, 98.84 parts of that metal will be deposited for every 32.31 parts of zinc dissolved in the battery, or in each cell, if a compound battery be used.

345. The reduction of copper has received more attention than that of any other metal. The art of electro-metallurgy originated with, and was, for a long time, confined to this

metal, and it is still more extensively reduced than any other. The single-cell apparatus (264) was long used for its reduction, and is still extensively employed; it is, however, inferior to the battery process.

346. In the choice of the salt of copper from which to reduce the metal, the operator must be guided by the kind of apparatus he intends employing, and the nature of the surface to be deposited on. If the single-cell process be adopted, the sulphate of copper should be used, if the nature of the surface to receive the metal will admit of it. The sulphate is the cheapest salt of copper, and as, in the single-cell process, the salt decomposed is not replaced by a corresponding quantity formed at the positive electrode, as in the battery process (275), a continual addition of the metallic salt is necessary, in order to maintain the strength of the solution. The continual deterioration of the solution, and consequent addition of the salt, renders it desirable to use the cheapest salt, and for this reason, the sulphate should be chosen.

347. Where the battery process is employed, the acidulated solution of sulphate of copper may be used, or a nearly saturated solution of the nitrate; if the surface receiving the deposit decomposes the solution, as iron in sulphate, or nitrate of copper, the operator must select a salt which is not acted on, although such salt may be inferior in every other respect.

348. The surface to be coated with copper must be treated or prepared by some one of the methods described in chap. vii.; if it is metallic, and it is not intended to cause the deposit to adhere, the precaution of exposing the surface to the air for several hours (228), or some equivalent treatment (229), especially if it be of copper, must not be neglected. If the adhesion of the deposit is desired, it may be effected by cleaning the metallic surface (230), if of copper; or by cleaning and amalgamating it (236), when of a dissimilar

metal, which is readily susceptible of amalgamation. If the surface is non-metallic, it must be rendered a conductor of electricity, by treating with plumbago (224) or phosphorus (216).

349. The mould, or surface thus prepared, must be connected with the zinc end of the battery, and a sheet of copper, to be dissolved, with the silver end. A single cell of the acid battery (109) may be used ; or when greater rapidity is required than can be obtained with such an instrument, a Daniell's (91), or a series of two or three of the acid battery may be used. The size of the plate of copper connected with the copper or silver end of the battery, should exceed that of the surface to be deposited on.

350. Immediately these conditions are complied with, the mould, if of metal, will be covered with a stratum of copper : if it be of wax, plaster of Paris, or any other black-leaded surface, this will not take place immediately ; but the precipitated metal will be observed, first to arrange itself round the conducting wire, and gradually to spread until it has covered the whole surface of the mould. The appearance of a mould on which the copper is spreading, is very beautiful : the process goes on with a rapidity varying with the quality of the black lead ; sometimes it will require an hour, or even a much longer time, to spread over the surface of a moderate sized medal ; at other times it vegetates, as it were, with extreme rapidity, and its progress may be observed with the assistance of a lens, or even with the naked eye.

351. It frequently happens, with bad plumbago, that the spreading at first commences rapidly, and declines, or ceases altogether, when a moderate sized metallic surface is formed. It also often occurs that the copper does not spread regularly ; that is to say, a number of branches form in different directions, leaving spaces between them uncovered ; it rarely happens that in such cases the experiment terminates successfully. If the whole surface does not become covered in



the course of two or three hours, the experiment may be regarded as a failure; for when the spreading of the copper goes on so slowly, a slight alteration of temperature may determine the expansion or contraction of the metal, before the whole surface is covered, and the copper detaching itself from the black-leaded surface, although the distance to which it separates is small, the edge of the metal not being in actual contact with the black lead, the process is completely arrested.

352. In placing a black-leaded surface in the electrotype apparatus, a very small plate, or even a wire, should at first be placed opposite to it as a positive pole. If this precaution be neglected, and a large plate at once introduced, the copper deposited near the wire connecting the mould with the battery will be of very bad quality, owing to the want of that proportion between the quantity of electricity passing and the size of the negative surface, which is essential to the production of ductile copper. As more of the surface becomes covered, a larger positive surface may be exposed.

353. After the apparatus has been at work a few minutes, it is advisable to examine the deposit, as its colour shews whether the process is going on properly or not. The appearance of electrotype copper is so characteristic that, when once seen, it can never be afterwards mistaken. If the arrangements of the apparatus are good, the metal will be tough and hard, and of a bright red colour, wholly unlike the copper reduced by ordinary processes; it may, perhaps, be more correctly described as of a pure orange colour; this, however, is only when the metal has the texture described. If the defective arrangement of the apparatus occasions a deposit of the brittle metal, its colour clearly indicates its character. Such metal has a dark, dull red appearance, wholly unlike the bright hue of the ductile metal.\*

\* A very interesting optical phenomenon may be observed, during the preci-

354. After the surface of the mould is completely covered with the deposit, the operation will not require further attention, excepting, of course, renewing the acid of the battery. It is necessary to be very careful in observing that no minute air bubbles are attached to the deep parts of the mould; these, of course, would spoil the deposited plate, as the copper cannot attach itself to those parts of the mould not in contact with the liquid. Sometimes the black lead (especially if a superfluous quantity be left in a deep part of the mould) will attach itself to one of these bubbles, and the copper spreading upon it, a perfect cast of the air bubble will be produced, and the operation rendered fruitless. These precautions having been observed, the experiment will proceed satisfactorily. If the surface on which the deposit takes place is small, a sufficient quantity of copper will accumulate in about six hours, supposing the apparatus to be in active operation. If the surface is a large one, such as a copper-plate, a much longer time must be allowed for the deposit to acquire additional thickness. It is only necessary to have a thickness sufficient to allow of the separation of the plate from the mould without

pitiation of copper in the electrotype. There are certain colours which, by mixture with other colours, produce white light; any two such are said to be complementary; thus red and green are complementary, because white is the result of their mixture; blue and orange are also complementary, for the same reason. This formation of white light by the mixture of such colours, though exhibited in the utmost perfection in some of the phenomena of polarised light, is not often observed otherwise; owing, principally, to the rarity with which the colours are presented in a pure state. This phenomenon may, however, be observed in great perfection in the electrotype; the solution of sulphate of copper is of an intense and pure blue; and the newly-precipitated *ductile* copper is of an equally pure orange; let the reader take a vessel containing the cupreous solution, and place it in the sun in order to have an abundance of light, and immerse in it, in a horizontal position, a piece of new electrotype copper—a plate or medal in the course of formation, for example; immediately the metal sinks beneath the surface of the blue solution the orange tint fades, and, by placing it at a proper depth, altogether vanishes, and the metallic plate appears intensely white; when nicely adjusted, the plate so much resembles plaster of Paris, that a person unacquainted with the nature of the experiment, would with difficulty be persuaded that it was not made of that substance.

risk of bending; any extra rigidity may be given more economically by the application of soft solder to the back, and by other means which will suggest themselves to every experimenter.

355. In depositing copper upon iron, a solution of the cyanide or acetate of copper should be employed. The only value of these salts is, that a die or surface of iron may be immersed in their solutions, without receiving injury by the corrosion consequent on the deposition of a film of metal by chemical action. They are much less convenient for ordinary purposes than the sulphate and nitrate, and should only be used when these salts are inadmissible. The acetate requires three or four cells of the acid battery for its ready decomposition; and the cyanide may be used at the boiling point with advantage.

356. By referring to the table of equivalents (32), it will be seen that 31.71 parts of copper will be deposited for every 32.31 parts of zinc dissolved in the battery, or in each cell when a compound battery is used.

357. Depositions of zinc may readily be obtained from either of the salts already enumerated (203), but the sulphate or acetate will be found to answer every purpose; and in consequence of its economy, the sulphate should be preferred. The only point to which attention need be particularly directed, is the neutrality of the solution. The salt formed by the battery (203) should not be used until it has been re-crystallized, as it is likely to be contaminated with acid, which interferes with the character of the deposit, occasioning a tendency to the production of the metal in the state of a black powder. A strong or nearly saturated solution may be used. The quantity of zinc deposited will equal that consumed in the battery, or in each cell of a compound battery, should the latter be employed.

## CHAP. XII.

ON THE PRODUCTION OF PRINTING SURFACES  
BY ELECTRICAL AGENCY.

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358. THE earliest impressions produced by voltaic precipitation, were from printing surfaces (15); and so admirably minute and faithful are the details of impressions thus obtained, that their production must ever constitute one of the most important branches of the art of electro-metallurgy.

359. There are two methods of producing printing surfaces by means of voltaic electricity; the design may either be made in metal, or of a non-metallic substance, and an impression in copper taken therefrom; or a metallic surface may be partially defended, by being coated with wax or caoutchouc (258), and connected to the silver or copper end of a voltaic battery, so as to constitute the plate to be dissolved (272). When the battery is excited, those parts of the metal which are not defended from the solution are corroded, while the coated parts are not affected. This process is sometimes called Voltaic Etching.

360. The circumstances to be attended to in copying engraved copper-plates, are sufficiently indicated in the preceding chapters; it is, therefore, only necessary to point out, briefly, the course to be pursued. Where practicable, a mould of the plate should be used instead of the plate itself; as time is thereby saved, and the risk of injuring the original plate avoided. A mould of lead may generally be made without difficulty (241). A mould obtained in this way, may be at



once introduced into the solution of copper (193), without risk of adhesion. A plate of copper, to be connected with the silver end of the battery, about equal in size to the mould, should be placed opposite to, and parallel with it. When the plate itself is deposited on, the greatest care must be taken to prevent the adhesion of the deposit, either by Mr. Spencer's process (229), or by exposure during several hours to the air (228). The deposit obtained by reducing copper on the original plate, serves as a mould or matrix on which a second deposition may be made, which latter will be a *fac-simile* of the original plate. The same care is requisite to prevent the adhesion of the second deposit to the mould, as in preventing the adhesion of the latter to the original plate.

361. Plates for engraving may be made by depositing the metal upon a burnished piece of copper. In this case, the precipitated plate will have a burnished surface like the copper on which it is deposited; or it may be precipitated on a plate not so prepared, and be afterwards treated exactly as ordinary copper is, for the use of the engraver. The arrangement of the apparatus necessary for the production of copper of a proper quality has been so fully pointed out, that it is unnecessary to repeat it here. Copper-plates intended for etching, when made by the electrotype process, are so superior to those of ordinary copper, that there can be no doubt the former will very soon completely supersede the latter. The electrotype metal is absolutely pure, and hence, in all chemical processes, is more uniformly acted upon than any other. The electrotype itself will demonstrate this. The copper forming the positive pole in the decomposition cell invariably presents a black surface during its solution, and a greater or less quantity of scaly matter, consisting of charcoal and other impurities, is invariably left behind, where thick plates are thus operated upon; but, if a piece of electrotype copper is used as a positive pole, its surface does not for a moment lose the beautiful orange colour so peculiar to it;

and, after the largest masses have been dissolved, not a particle of impurity is left behind—nay, the beautiful transparency of the liquid is not in the slightest degree impaired. Hence it is that, in the process of etching, the common or impure metal proves a source of anxiety, and often disappointment to the engraver, while he uses that precipitated by voltaic agency with absolute certainty of success. When the acid is applied to the former, its action is frequently intense in one place and feeble in another, and the etching is of necessity irregular; but with the latter the utmost uniformity of action prevails, and a corresponding regularity in the product results. From what has been said of the action of impurities in zinc, when treating of the voltaic battery, the reader will at once understand that the impurities may in some instances accelerate, and in others retard the action of the acid, according to their nature.

362. It has been proposed to prepare copper plates for etching, by means of a voltaic deposit, instead of the ordinary "ground;" it was believed that, by depositing an extremely thin film of gold on a copper-plate, so as completely to defend it, an artist might trace his design through this film with much greater ease and certainty than through the usual "ground;" and it was further supposed, that by exposing the plate to the action of acid in the usual way, those parts of the copper from which the gold has been removed by the artist's design, would be attacked and etched in, while the parts defended by the gold would remain unacted on. Experiment has, unfortunately, demonstrated the impracticability of this proposition, for although the gold is wholly unaffected by the acid, yet the parts which it covers are not secured against its action; the acid commonly insinuates itself between the gold and copper, and thus strips off the film of the former; or, in the few instances where this does not occur, the gold and copper form, with the acid, a voltaic combination (48), by virtue of which, the latter

metal dissolves most rapidly at those parts in contact with the former; and hence, before the lines have been corroded to a sufficient depth, they spread laterally, and the beauty of the design is inevitably injured.

363. A very ingenious method of producing printing surfaces by electro-metallurgical deposition, has been made by Mr. Palmer, and called by him "electrotint." It consists of a kind of painting, executed upon a stratum of semi-fluid composition, spread on a metallic plate: the surface of the composition is made a conductor of electricity; and a deposit of copper being made upon it, a metallic surface is produced, exhibiting the design originally drawn upon the composition, and capable of being printed from. By this process two kinds of plates can be produced: the design may be prominent, as in the case of a wood engraving, and the impression obtained from the surface of the design; or, it may be sunk beneath the surface of the plate, and the impression obtained as from ordinary copper-plates: the latter promises to be the more useful. We will describe the processes in detail.

364. To produce a plate to be printed from as an ordinary copper-plate, a stratum of a composition, consisting of one part of wax, two of lard, and one of lamp-black, is spread upon a plate of German silver, plated copper, or some other white metal, either polished, or having a "dead white" surface; to which plate has been previously soldered a wire, to connect it with a voltaic apparatus. Now, if a number of lines were drawn through this composition, so as to expose the white plate, and the whole surface made a conductor of electricity by black lead being spread upon it, a plate of copper can be produced from it, in which the lines drawn in the composition will project. If such a plate be printed from by a copper-plate printer, the impression produced will exhibit the projecting parts white, and the depressed ones black. In the mould, the lines drawn were white, for the



surface of the white metal was exposed, and the untouched parts were black, being the black composition; hence, in order to produce a design, it is only necessary to remove the black composition, so as to expose the white plate where whiteness is wanted in the printed impression, and where blackness is desirable, to leave the black composition; where intermediate shades are required, the composition may be partially removed, so that the white plate appearing through the thin stratum of the composition, gives the desired tint. To produce the effect of a picture, the artist takes the plate prepared as above, and by means of brushes of various degrees of hardness, removes the composition in such a manner, that the white plate appearing more or less through different parts of it, gives the effect he desires to produce. Different styles of handling may be adopted; by means of soft brushes, the smoothest tint may be produced; and by harder tools, coarser or bolder effects may be obtained. As the composition never sets or becomes hard, any defect may be remedied by spreading the composition over it, and working it again. Although the principle on which these paintings are produced is very simple, they are by no means easy of execution; for, although the effect wished may appear on the prepared plate, the impression produced from the copper-plate may have a very different appearance; for it is not only on the depth which may be given to different parts of the composition, but on the *character* of the surface that the depth of colour depends. Where perfect blackness, for example, is required, it is not enough that the composition be left unremoved—that will give the effect in the plate drawn on, and the electrotpe plate produced from it will exhibit a depression in that part—but when it is printed from, the ink will be removed by the printer's hand, and the part will print white. In such cases, it is indispensable to produce, by means of different tools, such a texture of surface that the ink shall be retained thereon.



365. The other kind of plate produced by this process, viz., that from the surface of which the design is to be printed, is produced by a process similar to the foregoing; the principal difference is in the preparation of the plate, which is in this case black, and covered with a white composition. The reason for this difference is obvious. In the former kind of printing, the projections were left white, and the depressions gave the dark tints; in the present case the projecting parts print black, and the depressions correspond with the lights of the picture; hence, it is necessary to have a black plate covered with a white composition, by removing which, the black plate becomes exposed and forms the dark parts of the design; where white parts are required, the white composition is left. A copper-plate may be blackened by being washed with a solution of hydro-sulphate of ammonia or chloride of platinum; and the white composition may be either a mixture of two parts of sulphate of lead, two of lard, and one of wax; or sulphate of lead and olive oil, mixed in such proportions as will give a proper consistence. The drawing may be executed with different tools, so as to produce various effects. After the drawing is made, the finest black lead is sifted on its surface, and any superfluity removed by an exceedingly soft and dry camel-hair brush; it is then exposed in the electrotype apparatus, and a metallic plate obtained from it.

366. A modification of this process has been invented by Mr. Palmer, by which the most elaborate subjects can be produced with a degree of perfection unattainable by the electro-tint process; it is called by the inventor, "glyphography," or engraved drawing.

367. In the process of glyphography, a smooth copper-plate, such as is used by engravers, is blackened by being washed with a solution of sulphuret of potassium, or hydro-sulphate of ammonia. A white composition, made by fusing together sulphate of lead, wax, and resin, is spread evenly

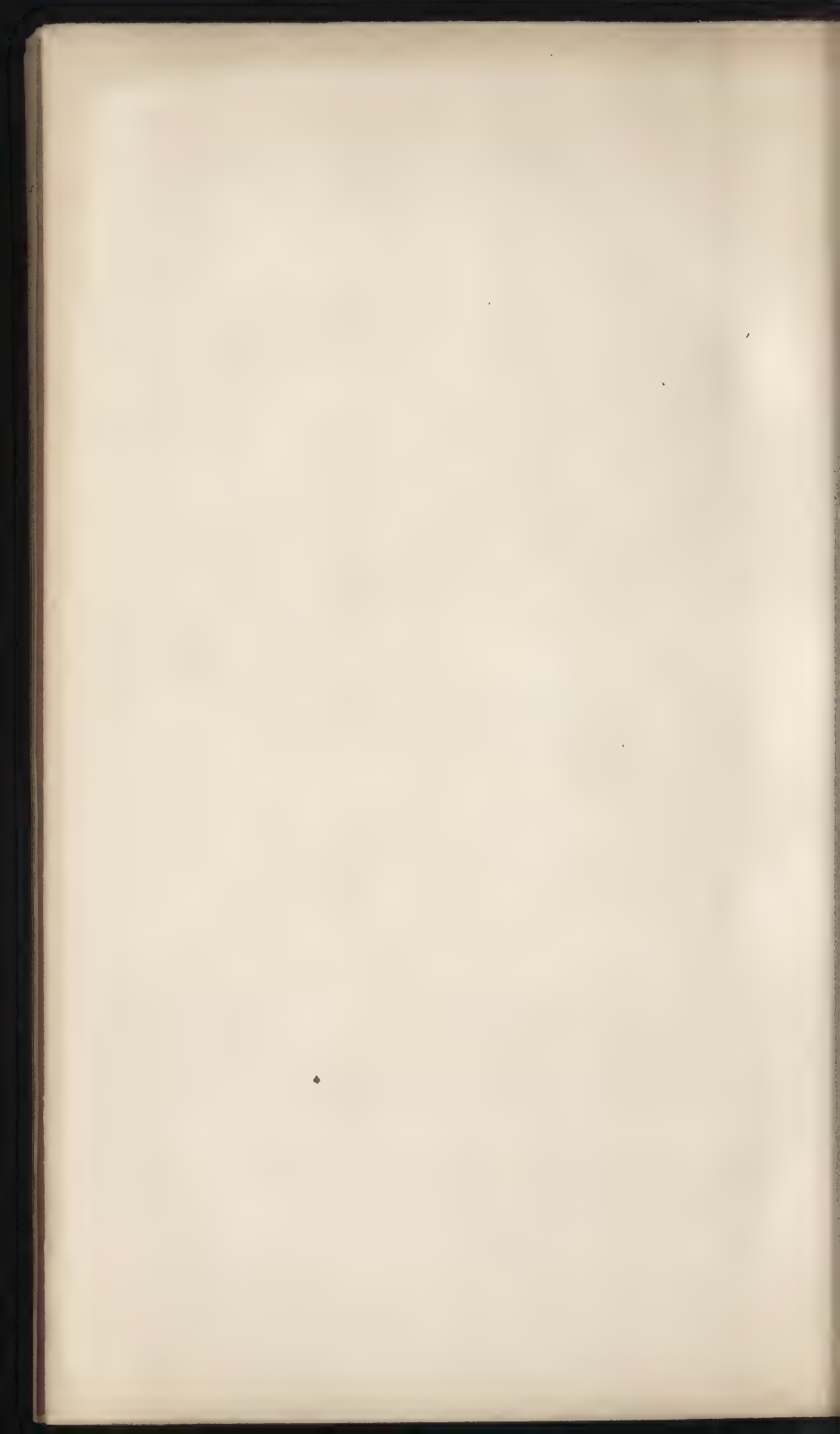
on the blackened plate, so as to form a stratum of about one-thirtieth of an inch in thickness. The artist proceeds to operate upon this plate with tools of extreme simplicity:—two or three steel points, of different degrees of sharpness, curved near the end, and some of them flattened at the point, constitute, with some pointed wooden tools, all that is necessary for the glyphographic artist. With these tools the artist cuts away the white composition, using the finer or broad-pointed instrument, as he wants fine or coarse lines, or the wooden points, if he wishes to produce free and bold lines. He can at all times judge of his work as it proceeds, for the removal of the white composition exposes the black plate, and thus produces the effect which the line made will produce in printing—a black line on a white ground.

368. When the design is completed to the satisfaction of the artist, a cast is taken from it; this may be done in two ways, either by plaster of Paris (246), or by precipitating copper on it; the latter, however, is preferable. To produce the cast, the surface of the composition is rendered a conductor of electricity by black lead (224), or any other suitable method, and a layer of copper deposited on it by the battery. When the stratum of copper is sufficiently thick, it is removed from the mould, and having been strengthened at the back, by having soft solder melted on it, is attached to a block of wood. The cast or impression thus obtained, is an exact counterpart of the design made by the artist; every line drawn in the composition is represented in the cast, by a raised line, the depth of which equals the thickness of the stratum of composition, that is to say, one-thirtieth of an inch; and when this surface is printed from, an impression is obtained exactly resembling, in effect, the design produced on the original plate.

369. When a cast has been taken in plaster of Paris from the artist's design, it is oiled, and a second cast taken; the latter is a *fac-simile* of the original plate, and a stereotype



PAUL AND VIRGINIA.

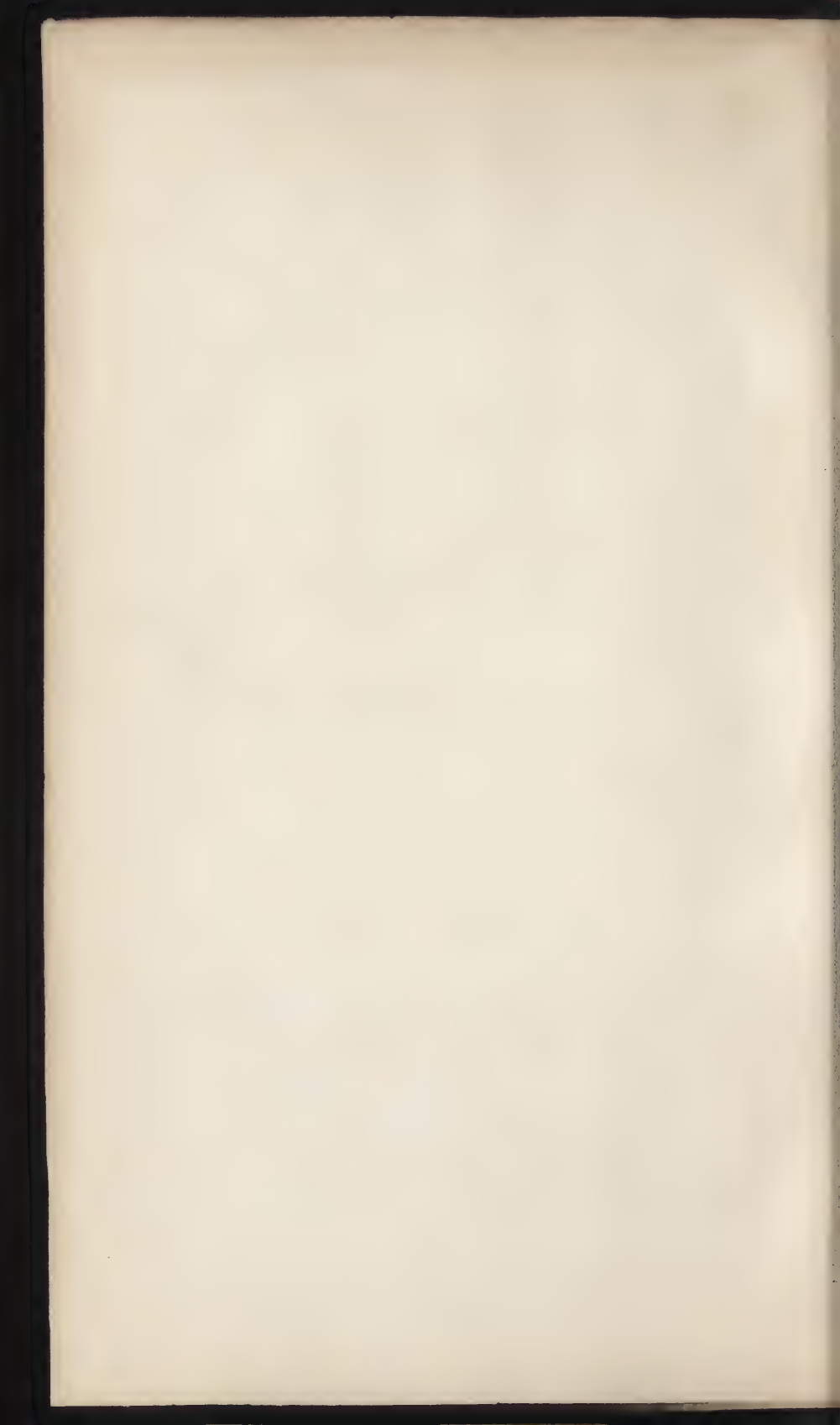






[ F. C. OSBORNE, TYP.

PALMER'S CYCLOGRAPHY. ]



impression may be taken from it by the ordinary stereotyper.

370. A glyphographic impression is printed from the surface, or projecting parts of the design, as in printing from wood blocks; it is therefore evident that the projections which print, being only one-thirtieth of an inch more prominent than the sunken parts, which are not intended to print, there is great risk of the latter printing, when there is any considerable surface exposed, as in broad lights. In order to avoid this, a quantity of composition is laid on those parts of the artist's design where he has left large surfaces untouched, so as to form projections, which, in the reverse taken, produce corresponding depressions, so deep as to render it impossible that they should ever print. It may, at first sight, appear difficult to lay on the composition without risk of injuring the design, but as it is unnecessary, in thus building up the broad lights, to approach the edges of the lines cut by the artist, there is no danger of obliterating any part of the design.

371. Glyphography is likely to supersede, to a considerable extent, the art of wood engraving; it possesses the advantage of economy, especially in complex subjects; and as the printing surface is produced from the artist's design by a series of processes, the success of which is not dependent on the manual skill of the workmen, the character of the original is preserved with an accuracy which cannot be attained by any other method.\*

372. The corrosion which takes place at the positive pole of the arrangement, has been made subservient to the production of printing surfaces. The art which has thus arisen is called voltaic etching.

373. The process by which etching on copper is ordinarily effected is so generally known, that it is only necessary to

\* The author is indebted to Mr. Palmer for the accompanying beautiful specimens of his invention.

allude to it briefly. The plate is covered with a thin layer of what is technically called "ground;" it is a composition, the principal ingredients of which are wax and pitch. It is applied by being rubbed over the copper-plate while heated. The artist traces the design he wishes to etch by means of a pointed instrument; the composition is removed wherever he has drawn, and the surface of the copper consequently exposed; the plate is placed in a vessel, and dilute nitric acid poured on it; the copper is dissolved wherever the acid comes in contact with it; and the lines drawn thus become permanently etched upon the plate. It is necessary to examine the work as it progresses, and to remove it from time to time, to "stop out" those parts where the lines are not required to be deep: this process consists in covering such parts with varnish or composition, which will defend them from the further action of the acid. This part of the work requires considerable attention, as much of the beauty and perfection of the result depends upon it. Notwithstanding the diligence and care of the workman in the production of the design, and the surprising address with which he "stops out," from time to time, those parts which have been sufficiently acted on by the acid, the operation is often more or less unsuccessful.

374. When treating of the purity of the electrotpe copper, we took occasion to notice the cause of the irregular action of the acid upon the metal reduced in the ordinary manner, and the superiority of that produced by voltaic agency. We are now about to describe a process by which the etching itself may be accomplished with far more ease, than by the common method, and with a certainty of success unattainable by any other mode of procedure.

375. From the various experiments which have been already described, the reader is familiar with the corrosion or decay of the copper, of which the positive pole of a voltaic arrangement is made (271); and he is also familiar with the



fact, that if the negative plate in a voltaic arrangement be covered with varnish, or some non-conducting substance, all action will be suspended at that part (257): accordingly, wherever a deposit of metal was not wanted in any of the experiments before described, we have directed such parts to be treated in this way. Precisely the same holds good with respect to the positive surface; only that part of it is acted upon which is in actual contact with the liquid, and the slightest film of any foreign substance effectually defends it from corrosion. It is upon these facts that the art of voltaic etching is founded.

376. The plate to be etched by the voltaic battery is prepared in the usual way, both with regard to the laying of the ground and the tracing of the design; it is then carefully varnished on the back and edges, and a wire is attached to some part where the copper is exposed: this must be done very carefully, as it is desirable to varnish it over afterwards. The wire is connected with the copper, silver, or platinum of a single voltaic battery, and a plate of copper of the same size, connected with the zinc, is placed in the solution, opposite to, and parallel with, the plate to be etched. The deposition of copper immediately commences upon the negative pole, and the lines, or other exposed parts of the positive plate, yield up metal to the solution. It is evident that it is immaterial whether the deposit on the negative plate is in the state of ductile metal or not, and the various circumstances with regard to the battery, which have been pointed out as essential to its production, need not in the present case be regarded; as the attention should be wholly directed to the conditions requisite to secure the uniform etching of the plate. The battery may be a single pair, as above stated, or a series of two or three may be employed; with the former the action will be slower than with the latter. The distance of the two plates in the solution will also materially affect the rapidity of the process; by placing them near

each other, a more rapid action will be induced, and by removing them to a greater distance, a corresponding retardation will follow. The copper-plate serving as the positive pole should be as near the size of the surface to be etched upon as may be; if it is larger, the lines near the edge of the plate will be more acted upon than those nearer the centre; and, on the contrary, if it is smaller, the centre will be more deeply etched than the edges. In some cases, however, such an effect is desirable, and it can be produced by the voltaic process far more accurately than by the ordinary method. A greater or less depth of the lines is effected in the common process, by stopping out portions from time to time—that is, covering with a varnish those parts which have been sufficiently acted upon by the acid, so as to defend them from farther action.

377. This mode of operating, however, does not enable us to effect a gradual transition from faint to deep lines; it is only by the voltaic process that this beautiful effect can be produced. If a plate be prepared, having a series of parallel lines drawn upon it, and be submitted to the action of the battery in the way already described, the lines will be etched with perfect regularity of depth, if the negative plate be parallel to it; but if they be inclined to each other, the lines will be made deep at that end where they are nearest, and will be faint at the end where they are most distant; an impression from such a plate will exhibit at one end a very dark tint, which, gradually fading, will leave the other end very nearly white. It is obvious, that this effect may be varied to a very great extent; if, for example, a prepared plate, having lines of uniform width ruled upon it, be experimented upon, and the negative pole in the decomposition cell be a circular disc, placed opposite to the centre of the plate, the lines will be deepest in the centre and fainter at the edges, and a surface printed from such a plate will exhibit a dark spot, the edges of which melt imperceptibly into the surrounding light: or

the reverse effect may be produced, if the negative be made of the size of the positive plate, or that to be etched, and have a circular hole made in its centre; the lines on the middle of the etched plate will be very faint, and those near the edge very deep: an impression taken from such a plate has a dark ground, with a luminous spot in its centre, the light of which becomes gradually fainter from the centre, and is eventually lost in the surrounding darkness.

378. The effects now described may be modified in several ways; indeed there is no limit to the varied effects of light and shade which may be thus produced; and it is scarcely too much to assert that the most beautiful designs may be produced by this mode of treatment, upon a plate on which parallel lines only have been drawn; for, by using a positive plate of the size of the negative or prepared plate, and perforating it in different forms, the etching will go on rapidly where the metal is presented to it; and the parts where no metal is opposed will be left more or less unacted upon; hence a proof from the plate will have a dark ground, and this design cut out of the negative plate will be left light. Or, if preferred, dark designs upon a light ground may as easily be produced; for if, instead of cutting out the pattern, the negative plate be cut into the desired form, the design will be deeply etched, and the impression will give a dark figure upon a light ground. Where it is desired to give very slight gradations of shade, or to produce in this manner complex figures, the better way of operating, is to make the surface of the negative plate to project in those parts opposite to which deep etching is required, and to be more distant where light is required. In other words, the negative plate should be embossed; and as it need not be thick, there is no difficulty in giving it the proper figure; the parts most prominent will give shadow, and those most depressed will leave light, and in proportion as the projections and depressions are more or less abrupt, will the transition from light to darkness



be more or less gradual. It is very important, however, for the experimenter to remember, that the distance between the plates affects the result in a very important manner; the closer they are, the more accurately will the design on the negative, be etched on the positive plate, and as they are gradually placed farther apart the figure on the former will become indistinct on the latter; indeed a plate, however embossed or cut away, will leave little or no trace of its figure on the positive surface, if it be placed very distant from it in the solution. The cause of this is sufficiently evident; when the embossed surface is very near the plain one, the distances of the raised and depressed parts from the plain surface are very disproportionate; but when placed at a distance, the disproportion becomes less, and at great distances, altogether insignificant. Now, if we suppose the action to be inversely as the distance, the effect of placing the plates near each other will be to render the disproportion between the distances of the different parts of the embossed plate from the plain one very great; and the difference in the amount of action on the opposed surface proportionably great; by placing them more distant, this difference vanishes, and with it the difference of action. It is evident that the same applies to perforated plates, or those cut in peculiar forms, and also to plain plates inclined to each other.

379. The advantages which the voltaic process of etching possesses over the ordinary one, are—its certainty of success,—the absence of gaseous matter on the surface of the plate, which in some degree interferes with the action of the acid,—and the clearness of the lines produced. We may also add, that the rapidity of the process can be regulated at the will of the operator,—that the progress of the etching may be at any time examined without inconvenience,—and that, besides permitting the regulation of the action by the process of stopping out parts of the plate, it affords a means



of effecting gradations of shade wholly unattainable by any other known method of etching.

380. One of the most beautiful applications of the voltaic process of etching is that made by Mr. Grove. This gentleman has succeeded in etching, by the voltaic battery, those beautiful pictures formed by the process of M. Daguerre. It is necessary to allude to the operation by which these pictures are formed, in order that the subsequent process of etching may be intelligible. A plate of silver, or of copper plated with pure silver, is carefully cleaned by the action of finely powdered tripoli and acid, and is afterwards exposed to the vapour of iodine, until, by the condensation of that element upon the silver plate, a film of iodide of silver, of a rose colour, is produced. The plate thus prepared, is extremely sensitive to light; and its sensitiveness may be increased by subsequent exposure to the vapour of bromine, in such a way as to determine the absorption of a determinate quantity of that element. The prepared plate is introduced into a camera obscura, so as to receive upon its surface the images of objects to which the camera is directed, and which are formed in the focus of its lens. The sensitive surface is allowed to remain under the influence of the light, for a time, varying with the season of the year, the clearness and brightness of the day, &c. Upon removal, it is exposed, in a close chamber, to the vapour of heated mercury, by which operation, the images of the objects thrown upon it while in the camera obscura, become developed; the mercury attaches itself to those parts where the light had fallen, and forms an amalgam, which has a crystalline texture, and a dead-white appearance. The plate is washed with a solution of common salt, or a solution of hyposulphite of soda; by which the iodine is removed, and the plate rendered no longer sensitive to light.

381. On examining a Daguerreotype plate, it is necessary to hold it in such a position that the incident light (the light by which it is illuminated,) shall not be reflected from its

whole surface to the eye ; otherwise the objects will not be visible, and the plate will only present a uniformly brilliant surface ; but, if the spectator places himself in such a position, with regard to the plate, that the light falling on it is reflected in another direction, the picture immediately becomes visible. The light parts in the objects consist of an amalgam of mercury and silver, and the crystalline surface of the amalgam scatters the light in different directions, and a portion of it consequently reaches the eye ; hence the whiteness of those parts : and the dark portions of the picture are those places where the mercury has not attacked the silver, and the light falling there is regularly reflected from the brilliant surface of that metal, and none of it reaching the eye, the plate presents that black appearance so peculiar to highly-polished metallic bodies. The intermediate lights and shades, are where the texture of the surface is more or less altered by the action of a greater or less quantity of mercury.

382. The chemical constitution of such a plate is, therefore, as different in different parts as is its physical structure, and it is by availing himself of this fact, that Mr. Grove has effected the etching of these beautiful productions. The Daguerreotype plate is varnished on the back and sides, and connected with the platinum of one cell of Mr. Grove's battery, and to the zinc is attached a plate of platinum, on which the fine powder of platinum has been deposited ; such a surface parts with the hydrogen liberated upon it, very freely. The two plates of an equal size are placed in a vessel containing a mixture of two parts of hydro-chloric (muriatic) acid, and one of water ; they are fixed at the distance of about one-fifth of an inch, and, by being made to slide in a grooved wooden frame, are maintained perfectly parallel, and at the proper distance from each other. In about thirty seconds the best effect is produced ; if the operation be continued much longer, the beauty of the picture will be impaired ; the etching will be deeper, but some of the fine

parts running into each other, the exquisite minuteness of detail for which these pictures are remarkable, will be destroyed. The plate, on removal from the solution, is washed in distilled water, and the brown deposit formed upon it removed by a dilute solution of ammonia; for this purpose it is placed in a shallow vessel containing the solution, and gently rubbed by soft cotton. The process is completed by a second washing and drying. These plates are not etched to sufficient depth to enable a printer to take good impressions from them, as the ink is not well retained in the deep parts, and the beauty of the plate is destroyed by the process of cleaning it.

383. Although this process is at present not sufficiently perfect to afford plates which can be printed from in the ordinary way, yet impressions may be taken in copper from Daguerreotype plates, etched by Mr. Grove's process. These impressions exhibit the minutest objects depicted on the original, and have altogether a pleasing effect.

384. In addition to the methods already described, by which printing surfaces may be obtained by electro-metallurgical agency, several modifications of these methods have been proposed; but as they have never been brought into common use, and are, in general, inferior to those already treated of, it is unnecessary to describe them.

## CHAP. XIII.

## ON VARIOUS APPLICATIONS OF ELECTRO-METALLURGY.

385. It is impossible to point out all the purposes to which the voltaic precipitation of metals is applicable; there is scarcely any manufacture to which it may not, in some degree, be applied; and for decorative purposes it has already been applied to an extent which even the most sanguine could not have anticipated. The principles on which success in this art is dependent, have been detailed in the preceding chapters; as well as those purposes to which it has been applied most extensively, and the practice of which constitutes a new manufacture.

386. The present chapter is devoted to a consideration of some of the processes in electro-metallurgy, the objects of which are less important, or less valuable, (though, perhaps, not less interesting), than those which have already been treated of in detail, such as the production of casts of specimens of natural history, copies of Daguerreotype pictures, and other applications, which are, in general, confined to amateurs.

387. In the early practice of the art, the deposition of films of copper on fruits, and specimens of natural history generally, was a favorite pursuit with amateurs, and each successive discovery, by which metallic depositions could be more readily formed on non-conducting substances, has added to the number of those who pursue this interesting branch of the art, as well as to the perfection of the specimens produced.



388. Very beautiful ornaments may be produced by depositing metals on fruits and flowers, and preserved specimens of insects and birds. These may either be preserved apart, or they may be grouped together, so as to form, by the contrast which is afforded by the difference in the metals with which they are covered, or the difference in the character of the same metal, the most beautiful ornaments, as well as the most exact form of the perishable objects from which they were produced.

389. Objects which are not of a very complex form, may be most conveniently covered with copper by means of plumbago (224); if, however, they are too intricate to admit of this treatment, the process by phosphorus (216) should be resorted to. It is, perhaps, more important in covering objects of natural history with metallic films to secure good plumbago, than in any other process; with medals, and casts, and inorganic bodies, the impression lost may generally be easily replaced, or if the object itself be introduced into the metallic solution, it receives, in general, no injury; and in case of failure, it is only necessary to repeat the process by which it is rendered a conductor: but with the objects in question it is otherwise; it is rarely that they can be operated on more than once; and if the experimenter introduce a specimen into the metallic solution without a successful result, he has generally the mortification, not only of failing to preserve his specimen, but of having rendered it in every respect worthless. It is for this reason that the black lead used for rendering specimens in natural history electrical conductors, should be of the best quality, and its fitness determined by previous experiment. The black lead should be laid on with a soft camel's hair brush; it may be spread very lightly, as an exceedingly thin coating is sufficient. With some objects, light coloured fruits in particular, the colour is so little altered by the treatment with black lead, that young experimenters in this art, despairing of the conducting power

of so thin a film, frequently injure or destroy their specimens, in the fruitless endeavour to give a thicker coating. The reader is cautioned against such a course.

390. It is well to use a tolerably intense battery in coating a black-leaded surface with metal, as the spreading of the deposit takes place with much greater rapidity, than when a feeble current is employed. A single cell of Daniell's battery, or a series of two or three acid batteries, will suffice. A small positive electrode of copper should be used when the article is first introduced into the cupreous solution. The best way of operating when a single fruit, such as an apple or a pear, is the subject of experiment, is to point the end of a wire and force it into the stalk; particular care must be taken to insure a connection between the wire and the black-leaded surface of the fruit. The specific gravity of most fruits being lower than that of water, they float on the surface of the liquid, unless means be taken to fix them beneath its surface. This may be effected by using a short stout wire to connect it with the battery; the proper bending of the wire will suffice to keep the fruit beneath the surface of the liquid. If the object be not large, it may be held in the hand until a film of metal has covered it, and then the precaution of using a strong wire is unnecessary.

391. If the black lead is good, the spreading of the metal over the black-leaded surface takes place with great rapidity; it may be seen to progress slowly by the naked eye, and with the assistance of a lens, its progress may be distinctly traced. It is only, however, with the best plumbago that such results are obtained. A moderate sized pear or apple may be held in the solution by the hand, for the purpose of becoming infilled, as the process ought not to take longer than a quarter of an hour or twenty minutes; if the spreading proceeds so slowly, as to require a much longer time for covering the article, the result will be more or less unsatisfactory, for the surface first covered continually augmenting in thickness

during the time it is in the solution, a considerable quantity of metal accumulates there, before other parts have received any deposit. The stratum of metal is thus of unequal thickness in different parts, and generally presents a greater or less degree of roughness where the greatest quantity of metal has accumulated. Where the film is required to be of considerable thickness, it must be allowed to remain in the solution a longer time than that before given.

392. When the object to be experimented on is of complex form, the treatment by phosphorus must be resorted to. The method of reducing metallic films on organic matters, first proposed by Mrs. Fulhame, and applied to electro-metallurgy by Mr. Spencer (214), may be resorted to when the object is large; but where its size admits of its immersion in the solution of phosphorus in bi-sulphuret of carbon (216), this process should be preferred to the other method. By the treatment with phosphorus, the most delicate flowers, insects, preserved birds, and indeed anything which will admit of immersion in a liquid, may receive a coating of metal.

393. When it is wished to preserve the form of the object coated, a battery of moderate intensity and quantity must be employed (314), with a solution of a good conducting power (193); a smooth, ductile metal will thereby be produced. If it is intended to produce ornamental articles, rather than accurate models of the coated articles, a strong solution (316), without acid, and a less powerful battery should be employed. The positive electrode may also be much larger than the surface to be covered (332).

394. Great variety may be given to these ornamental productions, not only by varying the character of the copper deposited, but by gilding or silvering the deposited metal. Silver may, indeed, be directly deposited on black lead, but with much less facility than copper; and it is advisable to obtain a film of copper first, and afterwards plate it with

silver. The silvering and gilding of the copper articles has been already sufficiently described.

395. No sooner had the pictures produced by M. Daguerre's process been presented to the world, than the idea of multiplying them occurred to several individuals; and considering the interest which must ever be attached to productions which, from their nature, must be correct representations, it is not surprising that scientific men eagerly sought the means of multiplying them, by a process which does not admit of inaccuracy in the copy. The process of multiplying these impressions which naturally first presents itself, is that of etching the metal plate on which the picture is formed, and printing from the etched pictures as from an ordinary copper-plate. The only process by which this can be done, with any approach to certainty and success, is that of Mr. Grove (382). There is no reason to expect that a more effectual or correct etching can be produced by any process; but the mechanical form of the etched surface, and the depth to which it is possible to corrode the metal, are so unlike the etching produced by ordinary means, that there is no hope of being able to produce a great number of perfect impressions from these etched plates.

396. One of the earliest efforts of the art of electro-metal-lurgy, was directed to the production of copies of Daguerréotype pictures by electric deposition; but the success attained was very imperfect. It almost invariably happened that the impression obtained on the deposited copper film was very faint; it often occurred that no picture was produced on it, and the original was generally destroyed; and thus, when the utmost success that could be expected was attained, the copy was procured at the expense of the original. The cause of these failures is sufficiently evident: a Daguerréotype picture, as produced by the original process, is simply a highly-polished plate of silver, on parts of which, mercurial



vapour has been deposited in such quantity as to destroy, more or less, the reflecting surface, and thus to produce a picture by the different degrees of reflection which take place at different parts. The mercury is at first very slightly attached to the silver, and although, after the lapse of months, it appears to amalgamate with it and become fixed, yet it never adheres so firmly that it may not be detached by the finger; hence, the mercury was removed from the silver, by the deposited plate of copper, and constituted the picture on it.

397. An admirable process of fixing Daguerriéotype impressions, so that they cannot be easily removed, has been proposed by M. Fizeau. By this process the pictures are not only fixed and prevented from fading, but they have a greater intensity, and less metallic reflection, than previous to fixing. As this process is indispensable to the production of electrotpe copies, it is given in detail.

398. Dissolve 15 grains of chloride of gold (167) in a pint of distilled water, and 45 grains of hypo-sulphite of soda in another pint of water; pour the solution of chloride of gold into the solution of hypo-sulphite of soda very slowly, stirring the mixture with a glass rod. The yellow colour of the mixture speedily disappears, and the solution becomes quite colourless; it is then fit for use. To fix a Daguerriéotype picture, it should be placed on a stand, similar to a retort stand, so that the flame of a spirit lamp may be brought under every part of it. If the picture has just been taken, it may be removed from the hypo-sulphite solution in which it has been washed, in order to remove the iodine, to the fixing stand; a small quantity of the fixing liquid is then poured on the surface of the plate, and the flame of a spirit lamp brought under it. The lamp is moved about so as to heat all parts of the plate equally. As the temperature of the plate rises, the picture loses a little of its intensity; but, by continuing the application of heat until the liquid has

nearly arrived at the boiling point, the picture again brightens, and is more vigorous than before the application of the fixing solution. This stage of the process is usually accompanied by the appearance of minute bubbles on the surface of the picture. The solution is now poured from the surface of the plate, which, after washing with distilled water, is dried in the usual way.

399. If the picture has been dried between the time at which it was taken and that of fixing, it is desirable to pour a few drops of alcohol on it, so as to wet it all over; it should then be washed in water, until the whole of the alcohol is removed. The object of this wetting with alcohol is to cause the adhesion of water, and afterwards the fixing liquid, to the plate. If the liquid be poured on a plate which has not been so treated, it will probably not adhere to the edges, but retire from them as though they were greasy. By pouring on a larger quantity of the liquid, such parts may be covered, but they will be stained in the process of fixing; hence the necessity of wetting the plate all over by the use of alcohol.

400. After treatment by the hypo-sulphite of gold, the picture becomes fixed to such an extent, that it is with difficulty removed by rubbing with the fingers; and the production of electrotpe copies is a work of extreme simplicity.

401. The plate must be allowed to remain many hours in a cool place after fixing (228), otherwise there would be risk of the adhesion of the deposite. It must then be attached to a wire by means of a binding screw, or in any other convenient way. The back should be carefully varnished, with some resinous varnish, or a solution of caoutchouc (258). The solution employed should be a saturated solution of sulphate of copper. It is of the utmost importance that the solution be perfectly clear, and is, therefore, necessary, not only to filter it in a situation free from dust, but carefully wash the vessel in which the precipitation is to take place. If any particles of dust or impurity rest on the surface of the

liquid, they attach themselves to the plate, in the act of immersing it, and no process of washing will remove them; the original and the copy are thus injured.

402. The battery used for copying Daguerriotype pictures should have considerable intensity, not only on account of the imperfect conducting power of the neutral solution of sulphate of copper, but from the circumstance that much of the beauty of the picture is dependent on the immediate infilming of the plate on immersing it in the solution. A single cell of Grove's battery (95), the size of the plates of which equals that of the pictures to be copied, will answer very well; or, in its absence, two or three cells of Daniell's battery (91). The wire soldered to the plate should be attached to the zinc of the battery, and the plate of copper to be dissolved, to the platinum or silver. The arrangements should all be completed before the introduction of the Daguerriotype, so that the moment it is immersed it may be coated with metal.

403. When the coating of copper is deemed sufficiently thick, the picture and deposit must be removed from the solution; while still in contact, they should be carefully washed in water, and dried with blotting paper. The complete removal of the sulphate of copper, and careful drying of the coated picture, are of importance, as neglect in these points may occasion the loss of both the picture and the copy. In order to remove the precipitated metal, it is necessary first to detach it from the edges of the plate; this may be best effected by cutting off, with a pair of scissors, a narrow strip all round the plate, the deposit may then be readily separated. If a drop of liquid remain on the edge of the plate, it will, on separating the deposit, insinuate itself between the surfaces, by capillary attraction, and stain both the original and the copy. It is, therefore, necessary to be particularly cautious in removing every trace of liquid before separation. The electrotype copy will exhibit, with surprising fidelity,

all the beauty of the original ; and it will differ from it only in being of a fine reddish brown colour, and exhibiting all the objects reversed, that is to say, the objects on the right in the original being on the left in the copy, and *vice versâ*.

404. The surface of the electrotpe copy must not be touched, and the impression should be removed, as quickly as possible, out of contact with the air, by being covered with glass.

405. Electro-metallurgy has contributed another process to the art of photography. The deposition of a thin film of gold on a Daguerréotype picture by electrical reduction, may be made to effect the fixing of the image, and to communicate a rich tone of colour, which cannot be attained by any other means. The specimens of Daguerréotype which are now commonly exhibited, and which have the appearance of being produced on a plate of gold, are simply ordinary Daguerréotypes, on which a thin film of gold has been deposited by the voltaic battery. When a Daguerréotype plate is made to receive a very thin coating of gold, the picture assumes a fine golden tint, without losing any of its intensity. It is scarcely necessary to remark that the process is a very delicate one, and should never be attempted on a fine specimen until the operator has, by previous experiments, assured himself that he is master of the art of electro-metallurgy. The solution used for the purpose of gilding Daguerréotypes, is that used in M. Fizeau's process, viz., a dilute solution of hypo-sulphite of gold (398). When the picture has been treated according to all the usual processes to which Daguerréotype impressions are subjected, it should be placed, face upwards, in a shallow earthenware or glass vessel. The solution of hypo-sulphite of gold (398) should be poured on it, and a wire from the zinc of a feebly-charged battery brought against one of its edges ; a plate of gold, connected with the copper or silver of the battery, being also brought into the solution, and held parallel with the



picture. Immediately all the connections are made, the operator should watch the plate closely, as its beauty depends upon the thickness of the film; if it is too thin, the picture has a faint, greenish colour, which is by no means agreeable; and on the contrary, when the coating is too thick, the picture loses intensity. By careful manipulation, and the suspension of the process at the proper point, the picture may be made to assume a fine golden colour, and at the same time preserve undiminished its primitive intensity. Instead of M. Fizeau's solution, the cyanide may be used, but, on the whole, the former is recommended.

406. It has been proposed to apply the electrical reduction of metals to the analysis of ores, and the detection of minute quantities of metallic bodies. It is doubtful whether, for general chemical purposes, the electrical reduction of metals is preferable to the methods usually employed by chemists. There are, however, particular occasions on which the chemist may conveniently employ the voltaic battery to effect the reduction of metals, which are otherwise reduced with difficulty. Mr. Edmund Davy has made a series of researches on the detection of metallic poisons by electric precipitation, in which he has demonstrated that the most conclusive evidence of the presence of those metals, the compounds of which are more commonly used as poisons, may be obtained by the use of a voltaic apparatus, and often with a facility and certainty that the ordinary methods of analysis do not afford.

407. In the detection of metals by voltaic agency, the most simple apparatus may be used: a small slip of zinc, and a similar slip of platinum, being, in most cases, all that is necessary. By means of this apparatus, the presence of gold, silver, mercury, copper, tin, lead, &c. may be almost instantly detected. If a drop of the liquid, supposed to contain either of these metals, be laid on the end of the strip of platinum, and the slip of zinc be brought in contact at the

same time with the liquid and the platinum, the metal, should any be contained in the solution, will be immediately reduced on the platinum.

408. So delicate is this method of reduction, that if half a grain of arsenious acid be laid on the platinum foil, with two or three drops of hydro-chloric (muriatic) acid, and touched in the manner described, with zinc, that part of the platinum on which the liquid rests will immediately become coated with metallic arsenic, and filaments of the metal will be mixed with the liquid. On exposing the platinum to the heat of a spirit lamp, the metal is readily recognised by the garlic-like odour so peculiar to it. It eventually volatilises in the form of arsenious acid.

409. By the treatment described, the metal arsenic may be reduced from solutions of the following of its compounds:—arsenious acid, arsenite of potass, lime, &c., arsenic acid, arseniate of potash, lime, &c., chloride and artificial sulphuret of arsenic. Some compounds of arsenic, the native sulphuret, for example, are little affected by hydro-chloric (muriatic) acid; in such cases, it is only necessary to heat them with nitric acid, previous to the addition of the hydro-chloric acid. The nitric acid should be used sparingly, and any excess expelled by heat, previously to the application of the hydro-chloric acid, as in case any free nitric acid be present, the precipitated metal will be re-dissolved immediately on the removal of the zinc.

410. Metallic arsenic thus reduced, may be obtained in the form of arsenious acid, by heating the platinum foil on which it is reduced, in a tube loosely closed at the end. On applying the flame of a spirit lamp, the metal is volatilised, and condensed on a cool part of the tube as arsenious acid.

411. The following experiment, by Mr. Davy, illustrates the extreme delicacy of this method of detecting arsenic. "I placed," says Mr. Davy, "on a new slip of platinum, weighing 22.14 grains, five drops of an aqueous solution

of arsenious acid, and three drops of muriatic acid; a slip of zinc being applied, the arsenic was soon reduced, and much of it adhered to the platina, which, after being washed in pure water and dried, acquired an increase of  $\frac{1}{350}$ th part of a grain. The platina was put into a small retort, which was then exhausted, twice filled with pure carbonic acid gas, and heated over a jar of the same gas, until all the arsenic rose and condensed in the upper part of the bulb of the retort as an extremely delicate whiteish film, exhibiting no metallic lustre, even by the aid of a magnifying glass; nor could this be expected from the minute quantity of arsenic present, and the extent of surface over which it was spread by sublimation. The platina was found perfectly clear, and of precisely the same weight as at first. Some pure water was put into the retort, and occasionally agitated in contact with the sublimate, but after thirty hours, a recent solution of sulphuretted hydrogen occasioned no change in the water. The actual quantity of arsenic attached to the platina in the foregoing experiment was ascertained to be  $\frac{1}{350}$ th part of a grain. But this is very far from conveying a just idea of the degree to which this mode of detection may be carried, for a single drop of the aqueous arsenious acid would have afforded ample evidence of the arsenic, as it respected colour, insolubility in muriatic and sulphuric acids, alliaceous odour, and volatility, which would give  $\frac{1}{2500}$ th part of a grain. Even this very minute quantity gives us by no means the extreme limits to which this truly microscopic method of detecting metals may be carried."

412. A very elegant plan of experimenting on the electrical reduction of arsenic, is to introduce the solution containing it into a platinum crucible, with an equal volume of muriatic acid; on touching the crucible and solution with zinc, the whole of the metal is reduced. The crucible should now be washed with pure water and dried; by placing a piece of plate glass on the top, and applying a spirit lamp to the bottom of the cru-



cible, the whole of the metal is volatilized, and condenses on the plate glass as arsenious acid. The deposition of the metal may be observed more readily by using a platinum crucible, gilded in the interior. The film of reduced metal often assumes the most variegated colours.

413. The compounds of mercury may be readily reduced by placing them on a slip of platinum, and adding a little dilute nitric, or hydro-chloric (muriatic) acid. On bringing the zinc in contact, the liquid metal is immediately reduced, and amalgamates both with the platinum and zinc. In this way mercury may be reduced from its oxides, chlorides, acetate, sulphate, cyanide, &c.; and the addition of acids may, in general, be dispensed with in experimenting on those compounds which are soluble in water.

414. The soluble compounds of lead may be reduced by treating their aqueous solutions by platinum and zinc; and the insoluble compounds by mixture with dilute nitric or hydro-chloric acid. The compounds of copper may all be reduced by similar treatment.

415. This reduction of metals by electric agency, is more valuable, as a means of analysis, from the circumstances that it is not at all affected by the presence of organic matter; and hence it is a valuable means of detecting the metals in cases of poisoning. Thus, arsenious acid mixed with tea, coffee, sugar, rice, milk, starch, potatoes, gruel, egg, isinglass, bile, saliva, butter, lard, oils, &c., may almost immediately be precipitated by zinc and platinum; in case of oily and fatty bodies, the mixture should be first boiled in an alkaline solution, and excess of muriatic acid added. These remarks apply to the metals generally.

416. Among the many subjects which have engaged the attention of electro-metallurgists, the reduction of alloys is one of the most prominent. From time to time it has been announced that the object had been effected, but investigation has, in every instance, demonstrated that the experiments



were fallacious. In the present state of electro-metallurgy there is reason to believe the reduction of alloys impracticable. There can be little doubt that, by directing a current through a solution containing salts of different metals, these different salts will be reduced, provided the quantities of the different salts, their relative conducting powers, and the intensity and quantity of the current be in the proper relation. But these conditions are not easily realised; there are no two salts of the same, or of different metals, requiring precisely the same electrical intensity for their decomposition, and hence, in a mixed solution, the current will be carried by the salt most readily decomposed, while the other will be unaffected. Supposing the current to be of such quantity and intensity as to be disproportionate to the salt of most easy decomposition, part of it will be conducted by the other salt, and both the metals will be deposited at the same time; but when there is much difference of conducting power, the current will be wholly conducted by the best conductor, and will reduce it in large quantity, or even in the state of black powder, rather than pass through the less perfect conductor.

417. It appears, then, that it is only by obtaining a solution in which the different salts are in precisely the proper ratio, by exposing such extent of surface at the electrodes that the current cannot be conducted by one of the salts, by using a positive electrode in which the metals are combined,—not in the ratio they are intended to have in reduced alloy,—but in such ratio that the same quantities will be taken into solution as are reduced, a ratio having reference to the susceptibility of their oxidation,—it is only by securing these conditions, combined with the use of salts having very nearly the same conducting power, (the last condition itself scarcely possible,) that the reduction of alloys can be even hoped for. It is not denied that it may be effected with some metals, in particular proportions; but the voltaic reduction of alloys of all the metals capable of alloying under the usual treatment, and

that in any desired proportion, is not only at present impracticable, but there is strong reason to fear will ever remain so.

418. It yet remains to be shown, that in those cases where two metals are reduced at one time from a mixed solution, a true alloy is formed; it does not necessarily follow that such is the case; on the contrary, all experience goes to disprove it. It has already been many times remarked, that one of the greatest difficulties the electro-metallurgist has had to contend with, is the want of adhesion of a reduced metallic film to the metallic body on which it was deposited; and even when the utmost care has been taken to clean the surface under experiment, so as to expose a pure metallic surface for the reception of the reduced metal, there is frequently no adhesion; and when there is, the application of an acid solution separates them, and demonstrates that, although there was the most intimate contact, there was no alloy. It is to be feared that a similar defect would present itself in the deposited mixture of metals: they may be in precisely the proper proportions, they may be most intimately mixed, but may yet not be alloyed; and it is difficult to suppose that anything short of that liquidity which heat alone can give, will allow of that intimate union between the metals necessary to constitute a true alloy.

419. Whether or not all the difficulties which present themselves in attempting to precipitate alloys will be eventually overcome, is a question which time alone can determine. It has, certainly, never yet been satisfactorily effected, and as far as our present knowledge extends, there is but a remote hope that it will be. It is, perhaps, fortunate that there would be little value in the accomplishment of this object, for however interesting it may be for science, the art of electro-metallurgy has little need of it.

## CHAP. XIV.

## ON THE COLOURING OF METALLIC SURFACES.

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420. THE films of gold and silver reduced on articles by the processes described in previous chapters, do not possess the colour necessary for commercial purposes. The gold is frequently of a dull colour, and the surface of the silver does not possess the brilliant whiteness, which, by an after process, may be communicated to it. The practice of colouring metallic surfaces has been long established, with regard to metals reduced by the ordinary processes, and the electro-metallurgist finds it necessary to treat articles in a similar manner, in order to meet the taste thus created. Although the colouring of the surfaces of metals is wholly unconnected with electro-metallurgy, the workers in this art are compelled to practise it, and it is hence deemed an essential part of their business. On this account, a brief description of the most successful processes is introduced in this treatise.

421. In order to give surfaces of gold the rich orange tint which they are generally seen to possess in their manufactured state, they should be treated as follows:—A mixture is made of five parts nitrate of potassa (saltpetre), two parts sulphate of alumina (common alum,) one part sulphate of zinc (white vitriol), and one part sulphate of iron (green copperas); these ingredients are mixed with water and gently boiled, until the mixture has about the consistency of cream. The articles are to be dipped in the semi-fluid composition two or three times, and allowed to become almost dry; they

are then heated in a stove, or on a hot plate of metal. The time during which they are exposed to heat, varies with the intensity of the heat and the colour desired to be given to the articles; the longer they are heated, the darker the colour will be. The articles are finally immersed in water, to remove the coating; they should here be well washed and rubbed with a brush.

422. A mixture produced by adding together acetate of copper (verdigris), sulphate of alumina (common alum), and bees' wax is sometimes used to colour gold red. The articles are coated with the mixture, and exposed to heat until it is burnt off. It is not so much used as the former.

423. Silvered articles may be coloured by various processes; the simplest and most effectual is that of M. Mouray. The articles are dipped in a saturated solution of bi-borate of soda (borax), and allowed to dry; a film of the salt is left on the surface after the evaporation of the water. They are immersed a second or third time, until a complete film of borax covers every part of the article; when large articles are experimented on, the solution may be applied by means of a brush. The articles thus treated must be exposed to heat, until the borax is perfectly fused; for this purpose, a heat nearly approaching to redness is required. After cooling, they should be immersed in dilute sulphuric acid, by which the borax is removed; they should be finally dried, by being shaken in heated sawdust, and warmed, in order more effectually to drive off all moisture. This process possesses the admirable property of preventing the rapid tarnishing of the plated articles. It was observed by those who first practised electro-plating, that the silver reduced from its salts by electrical agency, tarnished more rapidly than that manufactured in the ordinary way. This was ascribed to the purity of the silver, which was supposed to be favourable to its combination with the sulphurous and other vapours, by which it became tarnished. By M. Mouray's process, however, the tarnishing of the vol-



taic silver is prevented; and it is now scarcely, if at all, more readily tarnished, than that reduced in the common way. It appears that the discolouration was not produced by any external action, but that there remained in the pores of the reduced metal a small quantity of undecomposed salt, which suffers slow decomposition, and thus injures the colour of their surface. The treatment with borax completely removes this saline matter, and renders the metal unalterable from any internal action.

424. The communication of a bronze colour to copper, may be effected in a variety of ways. The simplest method of bronzing a production of the electrotype, is to rub it with dry plumbago or black lead immediately, or within a few minutes after its removal from the apparatus, and, after heating it till it becomes too hot to touch, rubbing it briskly with a hard brush (a tooth brush answers well for small objects) until cold. On afterwards removing the superfluous black lead by a linen rag, the bronze colour will be observed. The black lead should be applied with a brush, and care should be taken to avoid wetting any part of the surface during its application, as stains would be thereby occasioned. On rubbing the surface after heating, it frequently exhibits too dark a colour; this may in general be removed by vigorous rubbing, and slightly moistening the rag or brush used. If the copper has been exposed some hours to the air after removal from the solution, it cannot be treated in this way, until it has been previously cleaned by immersion in a dilute acid. The action of the black lead in producing this effect is not understood.

425. A very beautiful bronze colour, somewhat lighter than that produced by black lead, may be given by covering the surface with oxide of iron and heating it in a muffle. On removing the oxide of iron, the surface of the copper is found to have a very rich colour.

426. The application of hydrosulphate of ammonia to

copper produces a sulphuret of that metal, which is of a beautiful colour.

427. A dilute solution of chloride of platinum, on being applied to brass and copper, stains them of a very beautiful colour, by the deposition of a minute portion of platinum in an extremely divided state; it is wholly unlike the bronze produced by age, but exceedingly beautiful. Objects thus bronzed should be handled very carefully, for it is easily rubbed off.

428. In addition to these methods of colouring metallic surfaces, and which have come into common use, several other methods of effecting the same object have been more recently proposed by Mr. Talbot. It has often been remarked that gilding upon silver has a much finer colour than gilding upon an inferior metal. Mr. Talbot proposes to silver the surfaces of articles to be gilt, previous to gilding. This may be effected by immersing them in a solution of hypo-sulphite (189) or cyanide (185) of silver.

429. Boracic acid has also been proposed by Mr. Talbot for the purpose of colouring gilded articles. The acid is added to the solution of chloride, or other salt of gold, previous to the precipitation of the metal, and the colour of the gold reduced from the mixed solution, is finer than that obtained from the simple salt.

430. The processes already given have for their object, either the production of the colour proper to the metal under experiment, by the removal of the causes which interfere with its developement, or the heightening or modifying of this colour to suit public taste. There is, however, a process strictly electrical, which, although at present unapplied, is capable of producing colours of surpassing brilliancy. There can be little doubt that the fine effects which, under proper management, it is capable of producing, will, eventually, cause it to be extensively employed for ornamenting metallic

articles. The process alluded to is that by which electro- or metallo-chromes are produced.

431. It was first observed by M. Nobili,\* that the plates or electrodes used for transmitting a voltaic current through a metallic solution, became very beautifully coloured, under certain circumstances. If the current from a battery of four or five pairs be transmitted through a metallic solution, by means of a platinum wire, just immersed vertically in the solution, and a plate of polished metal lying horizontally, a very short distance below the surface of the liquid, the plate will be found, after a few seconds, to be coloured with a series of concentric rings, the centre of which is opposite to the point of the platinum wire. The effects may be varied in a variety of ways: the nature of the metallic solution, the metals composing the electrodes, the distance of the electrodes from each other, the end of the battery to which the plate is attached, are all circumstances which materially affect the results. The phenomenon may be presented at either pole; that is to say, the plate of metal on which these concentric rings are formed, may either be connected with the zinc or silver end of the battery; in either case they are formed, providing the other electrode exposes a small surface. The series of rings formed at the different ends of the battery are, however, essentially different. The colours obtained, are, for the most part, more brilliant when the plate of metal is connected with the copper or silver end of the battery. By using a steel plate in connection with the battery, and a solution of acetate of lead, a series of coloured rings is produced, which rival, in brilliancy, the Newtonian rings. In order to produce these colours in the greatest perfection, the steel plate, highly polished, should be placed on the bottom of a shallow vessel, a solution of acetate of lead should be poured into the vessel until it completely covers the surface

\* *Annal. de Ch. et de Phys.*, t. xciv., p. 280.

of the steel plate, a wire from the silver or copper end of the battery, must be brought against the edge of the plate, and a disc of copper, connected with the other extremity of the battery, placed on the surface of the liquid, over the middle of the steel plate; after a few seconds, the coloured rings will be observed. If devices be cut out of paper and laid on the steel plate, the colours will be limited to the space undefended by the paper; and a design will thus be produced of the form cut in the paper, and tinted with the richest colours.



## CHAP. XV.

ON THE VALUE AND PROBABLE RESULTS OF  
ELECTRO-METALLURGY.

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432. FEW arts have progressed so rapidly as that to the consideration of which these pages are devoted. A very few years have elapsed since curiosity was awakened, by the announcement of the first rude experiments, made for the purpose of usefully applying the voltaic precipitation of metals; and with such rapidity discoveries have followed each other, that we now possess an art so perfect, that we can scarcely imagine anything more to be desired. What changes have already been wrought in the metallic manufactures—what unhopd-for facilities in the multiplication of works of art!

433. In this, as in every other improvement, there are difficulties to be encountered, which experience alone can overcome—prejudices to be met, which time only can eradicate; but there are no difficulties which may not be surmounted—no prejudices which will not eventually yield. The blunders of the ignorant, and the failures of the inexperienced, have done much to retard the application of the art; and those who have imagined it their interest to oppose its progress, or affect indifference to its claims, have not failed to avail themselves of the opportunity thus presented: defects have been pointed out, while advantages have been overlooked; success has been hailed with but feeble praise, and failure visited with unmerited censure.

434. Of the value of the art there is much difference of

opinion; and where commercial interests are so opposed as they necessarily must be, in the advance of that which not only opens new branches of manufacture, but threatens to supersede others, it is not surprising that some should be slow to acknowledge real merit, and others loud in defending that, which the candid confess to be imperfect. It is, perhaps, to be regretted that the art was made subservient to manufacturing purposes, before all its details had been sufficiently investigated; but it is, on the other hand doubtful, if without such application, there would have been sufficient inducement to carry out the necessary experiments; nay, it is certain that many discoveries, by which the art has been improved, would never have been made, but through operations on a large scale.

435. The early practice of the art was principally confined to the multiplication of engraved copper-plates, medals, and coins, and the eagerness with which the novel process was practised, occasioned much mischief; valuable plates were entombed in masses of metal, from which they can never be disengaged, and the most valuable relics of antiquity have been disfigured by the rude attempts of the inexperienced. And even when success seemed fully attained, disappointment frequently followed; the copy of the engraved plate was sometimes so soft as to be wholly unfit for use, and the model of the coin so brittle that it broke under the most careful treatment. But these defects have their origin in the operator, not in the process; and the most uniform results, can with certainty be obtained, by the exercise of an amount of skill not greater than that, required to conduct the most ordinary manufacturing process. Until the other arts have obtained a perfection which renders failure impossible, the reproach of uncertainty, which the imperfect productions of the ignorant have brought on electro-metallurgy, is an unjust one.

436. The strongest prejudice with which the art has had

to contend, is that directed against electro-plating and gilding. The electro-metallurgist is constantly taunted with the want of adhesion between the deposited film and the metal to which it is attached. It is, unfortunately, true that many of the early specimens of this branch of the art were very defective. On the application of heat, the metallic film frequently rose in blisters, and a cut or scratch, which perforated the deposited metal, was commonly the signal for the detaching of the whole coating. This was not merely an acknowledged imperfection, but a defect which threatened to destroy the otherwise great value of the art. But investigation has furnished a key to the solution of the difficulty; and, by the treatment described in the foregoing pages, an adhesion may be effected with perfect certainty, which time has shown to be more than sufficient for all purposes. The adhesion may not be equal to that of ordinary plating, where the two metals are fused together, but experience has shown it to be abundantly sufficient. The art is, therefore, no longer chargeable with this imperfection; and the representations which are even now made respecting the inefficiency of the process, do not arise in a desire to remove an existing defect, but in an endeavour to perpetuate a vulgar prejudice.

437. We cannot better form an estimate of the probable results of the art, than by reviewing what it has already accomplished. It has furnished us with processes by which the most elaborate works may be copied in metal, with an accuracy and certainty to which no previous processes have any pretension; and it is applicable, in many instances, where every other is ineffectual. The metals with which its operations are most favourably carried on, are those whose working, under such circumstances, would be impossible in any other way. In what way could we obtain impressions in copper, silver, and gold, of the various objects to which the electrical precipitation of metals is applicable, from copper-plates, coins, medals—the endless variety of objects from

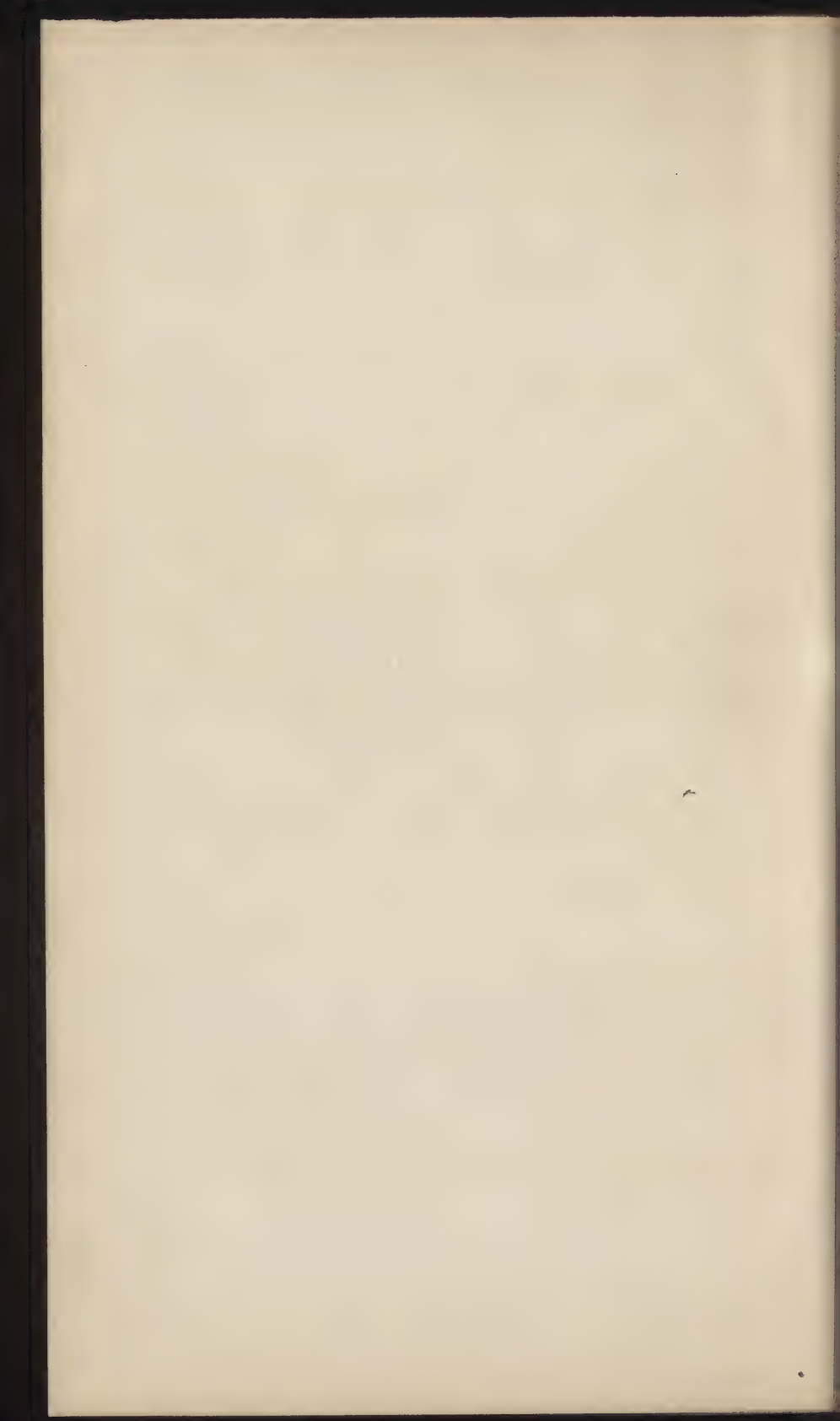
inanimate, as well as animated nature—fruits, which, in a few hours, shrink from their original form—flowers, which droop and wither in a few minutes, and whose delicate structure can bear no ruder treatment? In what way can we multiply the productions of Daguerre's inimitable process?—pictures which are destroyed or injured by the gentlest touch of the finger, but which may be faithfully copied, in all their beauty and detail, by electro-metallurgy, and that, too, without injury to the original.

438. But the most admirable application of the art is in the processes of gilding and silvering. The process of electro-plating offers extraordinary facilities in the production of superior designs. In the ordinary method of plating it is usual to construct a plated article as far as possible from plated sheet metal, while the edges and ornamental parts generally are completed, by soldering thereto parts, either stamped in plated metal, or in silver. By such a method of manufacture the designs must necessarily be limited, being confined to such ornamental forms as could be produced by stamping or otherwise fashioning sheets of metal. In the process of electro-plating no such restriction is imposed; the artist produces a design without being fettered with any difficulties of manufacture, knowing that any form is equally capable of receiving a coating of silver by the voltaic process. To what an extent have manufacturers already availed themselves of this great advantage; and what an improved taste must such superior designs create! We already see the most elegant shapes and the most elaborate workmanship bestowed upon articles which, in the old method of manufacture, could only assume one series of monotonous forms. The plain surfaces of many plated wares, have now become shapes of classic elegance, and the feebly chased ornament, has given way to the boldest design. No manufacture, in the whole course of its history, presents greater contrasts than that presented within two or three years in the manufacture



of plated wares. The artistic skill which is now exercised in the production of designs, knows no limit but that of a refined taste ; and its productions seem to acquire new beauties by contrast with the frigid, unmeaning forms, to which, in many instances, it was previously limited.

439. Although, in the production of gilded articles, the voltaic process cannot be said to have achieved so much for art, it has taken part in the production of a change incomparably more important. The pernicious process of gilding by an amalgam of mercury and gold, had, to some extent, been superseded by the introduction of other processes ; but there was none possessing all its advantages, until the voltaic reduction of gold was introduced. The object is at length attained,—the voltaic precipitation of gold can be effected with far greater economy than the mercurial process, and it is applicable in many instances where the latter fails. It is much to have introduced a process superior to any previously known, but it is much more to have banished an art whose practice is inseparable from human suffering.



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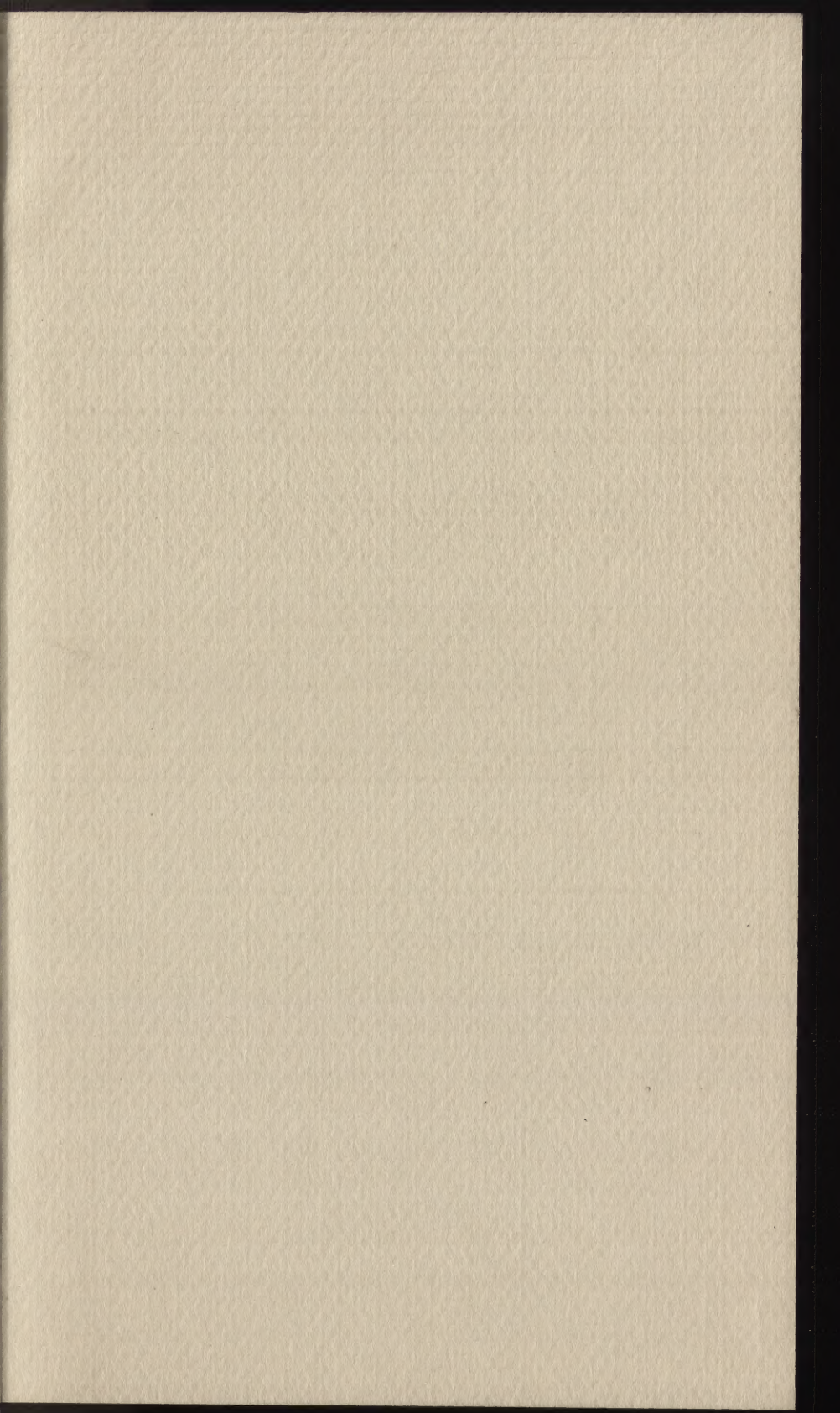
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